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Holistic recommendations for future outdoor thermal comfort assessment in tropical Southeast Asia: A critical appraisal

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ABSTRACT

Global climate change, rapid urbanization and population explosion in major cities of Southeast Asia (SEA) are negatively impacting the well-being and liveability of the public in terms of deteriorating outdoor thermal comfort (OTC) levels. However, the available scholarly studies on OTC in the tropical region are insufficient. There is great potential for OTC studies to be used as indicators to measure the sustainable liveability of contemporary cities. As such, there is an immense need for more studies to be conducted in the tropical regions. However, the assessment approaches undertaken in the last decades clearly indicate that there is a need for improvisation. By considering this, this paper provides an overview of published studies that evaluated thermal comfort conditions in the outdoor setting in the tropical context of SEA. Methodological discrepancies and shortcomings are highlighted and discussed to propose a holistic approach for future OTC studies in SEA. The implementation of the proposed holistic approach in the upcoming studies will be beneficial for the improved reliability and integration of findings from studies conducted in various outdoor settings and localities within SEA.

1. Introduction

Global climate change and rapid urbanization in major cities are deteriorating the liveability status of the population living in it. Currently, more than 50% of the world population live in urban areas and that number is expected to increase to 6.4 billion by 2050 (Department of Economic & Social Affairs, 2014). The vast expansion of major cities in tropical regions such as Southeast Asia (SEA) encourages immigration (both locally and internationally) because of more job opportunities, better health and education facilities, and other attractive factors. Consequently, the population density increases significantly, especially within the tropical cities. As half of the world population is currently concentrated in the tropics (Siemens, 2011), escalating studies are focusing on identifying new strategies to enhance the liveability of urban communities in the tropical cities (Ignatius, Wong, & Jusuf, 2015).

Urban Heat Island (UHI) is a phenomenon commonly associated with rapid urbanization (Mochida & Lun, 2008). The increasing UHI intensity in tropical cities is known to deteriorate the urban environment, urban ecosystem and human well-being (Yang, Wong, & Lin, 2015). The replacement of dense greeneries with high-rise buildings causes a hike in urban air temperature that induce human thermal stress in urban spaces (Yang, Nam, & Sohn, 2016; Yang, Niyogi et al., 2016; Yang, Wong, & Li, 2016). It is now emerging as one of the climatic threats to the poor urban population in developing countries.

The declining outdoor thermal comfort (OTC) levels is one of the direct impacts of UHI phenomenon (Hanipah et al., 2016; Morris et al., 2016; Qaid, Bin Lamit, Ossen, Raja Shahminan, & Shahminan, 2016) that should be of public concern. A constant rise in temperature within tropical city centres will lead to the aggravation of heat waves, thermal discomfort, heat-related illnesses and even mortalities. Worst still, the tropics are known to be hot and humid throughout the year. Vulnerable people, including children, elderlies, pregnant women and those with existing health conditions are at a higher risk due to the deterioration of OTC levels (Acero, Arrizabalaga, Kupski, & Katzschner, 2013; Nakano, 2015; Wilby, 2007). From the perspective of urban planning, thermal comfort/discomfort and heat stress are decisive parameters influencing the use of outdoor spaces which can be translated into the improvement

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of quality of life (Ali-Toudert, Djenane, Bensalem, & Mayer, 2005; Aziz, Ahmad, & Nordin, 2011; Epstein & Moran, 2006; Nikolopoulou & Lykoudis, 2006; Nikolopoulou, Baker, & Steemers, 2001).

To date, bio-meteorological studies of human thermal comfort have put more emphasis towards the indoor setting over the outdoor (Yang, Wong, & Jusuf, 2013a) or semi-outdoor settings. A significant lack of studies on human OTC in the tropics (Ahmed, 2003; Chow, Akbar, Heng, & Roth, 2016; Johansson & Emmanuel, 2006; Lin, 2009; Lin, Matzarakis, & Hwang, 2010; Makaremi, Salleh, Jaafar, & GhaffarianHoseini, 2012; Morris et al., 2017) highlights an urgent need for more scholarly studies to be conducted in the tropical cities. In fact, the knowledge of human bio-meteorology in urban planning is an important investment for the development of resilient cities and communities against global climate change in near future (Ndetto & Matzarakis, 2017). Therefore, it is crucial for the urban planners and designers to be well equipped with adequate knowledge on OTC to provide efficient urban designs that prioritize the functionality and usability of an open space in a tropical city (Roth, 2007). However, an initial literature survey of OTC studies has highlighted several methodological caveats that need to be addressed.

Thus, a critical review on the assessment approach of OTC studies in the tropical context of SEA was conducted to discuss the methodological caveats and potential solutions. This review has several specific objectives. Firstly, this review aims to provide a general notion of OTC in a broader context. Secondly, this review will provide a critical appraisal on the methodological discrepancies of OTC studies in SEA. Thirdly, a holistic approach for the improvements of future OTC studies will be proposed. This review will also highlight future research directions of OTC studies in SEA. It is noteworthy that this review only included peer-reviewed studies on OTC from the tropical countries in SEA.

2. The notion of OTC

Thermal comfort in the urban outdoors or OTC, refers to the comfort level of a man with regards to the thermal environment at an exposed outdoor environment. The determination of thermal comfort at outdoors is complex because of the multifactorial interactions between a man and his constantly varying environment.

2.1. Definition of thermal comfort

Thermal comfort is a subjective evaluation that is defined as the condition of mind that expresses satisfaction with the thermal environment (ANSI/ASHRAE 55, 2013). The heat exchange that occurs in between the human body and the environment follows the laws of thermodynamics where the core body temperature is maintained within the range of 37 ± 1 °C for human body to function optimally (Epstein & Moran, 2006). The thermoregulatory capabilities of the human body to maintain body core temperature is important to avoid potentially hazardous health implications such as heat stroke (Kurazumi, Ishii, Fukagawa, Kondo, & Aruninta, 2016) and other heat related illness.

2.2. Layers of thermal environment

The thermal environment surrounding a man can be classified into several layers according to the level of environmental control applied. Commonly, the layers of thermal environment surrounding a man are classified into outdoor environment, semi-outdoor environment and indoor environment as illustrated in Fig. 1 (Nakano, 2003).

The outdoor environment is the outermost layer where no artificial adjustments are made. On the other hand, the indoor environment is the space enclosed within a building in which heating, ventilation and air conditioning (HVAC) engineers have mainly dealt with to provide desirable thermal environments for the occupants. The indoor environment is further classified into occupied zone and personal or task zone. Moderately-controlled environments located in between indoor and outdoor layers such as lobbies, courtyards, atriums and verandas with maximum exposure to the outdoor environments are referred to as semi-outdoor environments (Yang et al., 2013a).

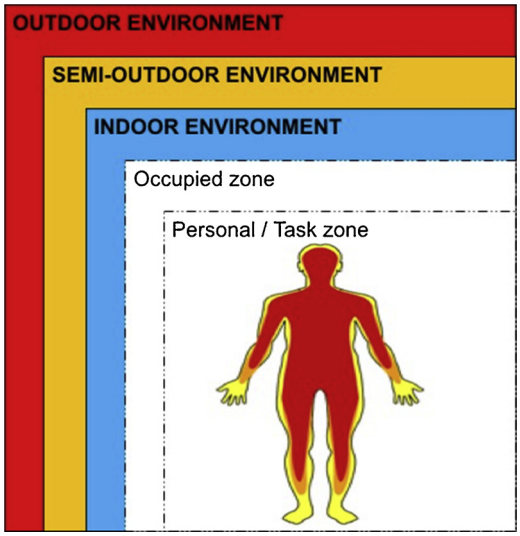

Fig. 1. Layers of thermal environment surrounding a man.
Source: Modified from Nakano (2003).

Despite a well-known distinction between different thermal environments surrounding a man, limited attempts were made to understand the thermal comfort differences in between these indoor, semi-outdoor and outdoor environment zones (Yang et al., 2013a). As people tend to react differently in diverse thermal environment according to their ability to control or adapt to surroundings, repeated exposure can cause a person to be acclimatized (behavioural and psychological adaptation) towards a thermal environment. An overall understanding of the interaction between the environment and the occupants will ensure achievement of suitable thermal comfort in any thermal environment.

2.3. Approaches in thermal comfort assessments

Thermal comfort in various thermal environment can be evaluated using various approaches depending on the levels of assessments and their influencing factors as shown in the general framework of Chen and Ng (2012) in Fig. 2.

In general, OTC assessments can be classified into four levels such as physical, physiological, psychological and social behaviours. The physical level considers the interaction of human body with the surrounding environment which is assessed through in-situ ground measurements or modelling of microclimate parameters such as air temperature (Ta), relative humidity (RH), wind speed (v), and solar radiation (I). On the other hand, the physiological level of assessment is the study of thermoregulatory responses of the human body towards the thermal environment. Usually, physiological assessment is conducted by monitoring human physiological processes (skin temperature, metabolic rate, etc.) or modelling via thermal comfort indices. In contrast, psychological level of assessment considers the feeling of the person in terms of comfort, sensation, perception, acceptance and preference towards the thermal environment. Commonly, psychological assessment is done using questionnaire surveys and interviews. The psychological responses cannot be predicted through physical and physiological assessment alone but it is common to correlate both physical and physiological responses to psychological responses in the previous studies (Parson, 2003). Lastly, the level of assessment in terms of social behaviour comprises of both objective and subjective measures which is assessed through observations and interviews. Unlike the assessment of

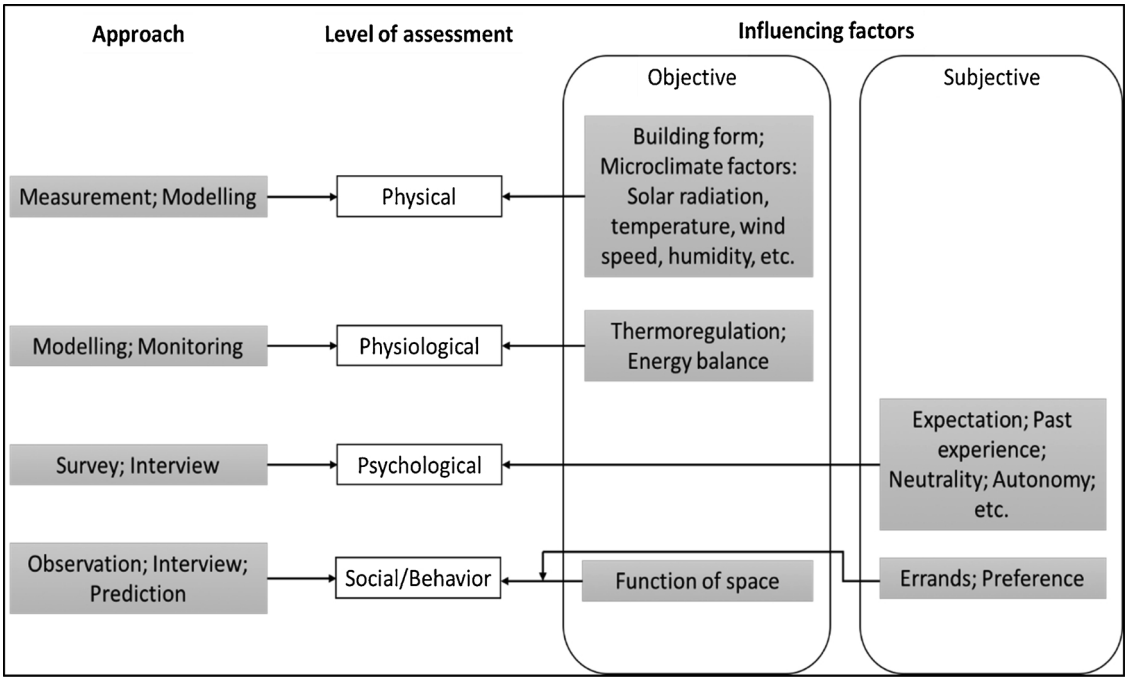

Fig. 2. A general framework for OTC assessment.
Source: Chen and Ng (2012).

physical, physiological and psychological level which is individually subjective, social behaviour studies requires large scale of study sample as it defines the thermal environment or thermal comfort acceptance as a norm of the society.

3. An introduction to SEA

SEA is an actively developing region in Asia which is one of the most populated continents in the world. According to the Gross National Income (GNI) per capita, most of the SEA countries are in the lower-middle income group with only few countries in upper-middle and high-income group as shown in Table 1.

The rapid urbanization in city centres of SEA countries has caused several negative impacts with the formation of UHI being one of them. Besides that, prediction of future urbanization impacts reveals that the daily minimum air temperature in SEA will be influenced more greatly than the daily maximum air temperature (Van Doan, Kusaka, & Ho, 2016) indicating more frequent heat stress cases in near future. Considering a large population within SEA, the knowledge on OTC has become imperative to ensure effective mitigation and adaptation measures to overcome the expected rise of heat stress in the future.

3.1. Geographical location of SEA

SEA is one of the sub-regions of Asia (Fig. 3), consisting of countries that are geographically centred among south of China, east of India, west of New Guinea and north of Australia. The region lies near the intersection of geological plates, with heavy seismic and volcanic activity.

Table 1
Countries in Southeast Asia according to their GNI per capita.
Source: World Bank Indicator (2017).

Low-income	Lower-middle-income	Upper-middle-income	High-income
N/A	Cambodia Indonesia Laos Myanmar Philippines Timor-Leste Vietnam	Malaysia Thailand	Brunei Singapore

3.2. Climate zones of SEA according to Köppen's climate classification system

In general, countries in SEA exhibit tropical hot-humid climate with sufficient amount of annual rainfall with large and relatively constant annual net solar radiation. In many locations, the seasonal monsoon effect in a year causes the occurrence of wet and dry seasons. According to the Köppen's climate classification system, countries in SEA experience Type A-Equatorial climates. The monthly mean temperature of these countries are at least 18 °C and above (Peel, Finlayson, & Mcmahon, 2007). While most of the countries in SEA experience tropical monsoon climate (Am) and tropical rainforest climate (Af), there are exceptions in the northern region of Vietnam and Myanmar, which experience humid subtropical climate (CWa) due to their geographical location situated further from the equatorial. Fig. 4 illustrates climates of SEA according to the Köppen climate classification system.

4. Overview of methodological approaches of OTC studies in the tropical context of SEA

A topic search was conducted using online search engines such as Web of Science, Wiley Online Library, Scopus and Google Scholar to identify relevant literature using the keywords such as "thermal comfort", "thermal acceptance", "thermal perception", "thermal sensation" and "thermal preference". Then, an abstract screening is done to exclude irrelevant literature. The references of the included papers was double-checked to include missing papers which are of interest. Papers which satisfied the two following criteria are included for review. Firstly, the study must be conducted in any one of the countries within the tropical climate zones of SEA. Secondly, the papers should provide a proper description of methodological approach of thermal comfort assessment at outdoor spaces.

A total of 21 studies between the years 1997 and 2016 are identified

Fig. 3. The region of SEA.
Source: Google Map (2017).

and included in this review. A detailed description of OTC studies conducted in SEA are tabulated in Table 2.

There is an obvious knowledge gap concerning OTC in SEA where most of the studies are concentrated in Malaysia (10) and Singapore (6) while countries such as Indonesia (3), Vietnam (1) and Thailand (1) have three or lesser studies. No research publication was found from other remaining countries. The economic status of each country as shown in Table 1 may be one of the reasons explaining the fewer number of OTC related publications in SEA. The general framework (Fig. 2) as proposed by Chen and Ng (2012) is used to classify the OTC

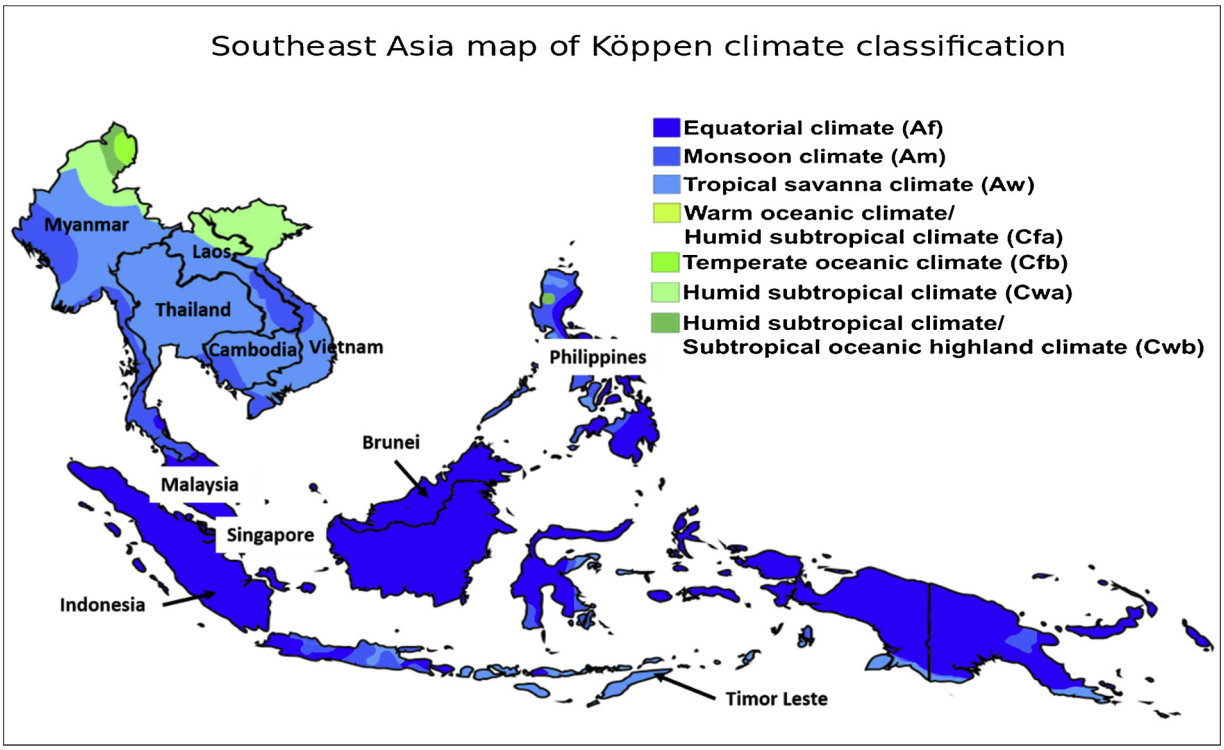

Fig. 4. SEA according to Köppen climate classification.
Source: Modified from Ali Zifan (2016).

Table 2
OTC studies conducted in the tropical context of SEA

Country	Study area	Urban morphology	Subjective assessment	Thermal comfort indices used	Level of assessment	Source
Malaysia	Kuala Lumpur	Courtyard (Semi-shaded, open area and covered area) and recreational garden	Yes	Not evaluated	Physical and psychological	Bakar and Gadi (2016)
	Alor setar, Kuantan and Subang	Not stated	No	UTCI	Physical, Physiological	Hanipah et al. (2016)
	Putrajaya	3 urban areas (dense low-rise and high-rise residential area and boulevard street) with 1 sub-urban area (school yard facing open area)	No	PET	Physical, physiological	Qaid et al. (2016)
	East coast (Merang Sutra Beach Resort) and West coast (Lexis Port Dickson) of Peninsula Malaysia	Not stated	Yes (Online survey)	Not evaluated	Physical, psychological	Jabarudin and Harith (2015)
	Bayan Lepas, Penang	Not stated	No	Not evaluated	Physical	Nordin and Hassan (2015)
	Putrajaya and University Technology Malaysia (UTM)	Boulevard street and 4 types of building layouts (in front, between, within and surrounded by the building)	Yes	THI	Physical, physiological, psychological	Din et al. (2014)
	Shah Alam, Selangor	Lake Garden	Yes	HI	Physical, physiological, psychological	Nasir et al. (2013a)
	Shah Alam, Selangor	Lake Garden	Yes	AT	Physical, physiological, psychological	Nasir et al. (2013b)
	Shah Alam, Selangor	Lake Garden	Yes	PET and AT	Physical, physiological, psychological	Nasir et al. (2012)
	University Putra Malaysia, Selangor	Shaded outdoor spaces	Yes	PET	Physical, physiological, psychological	Makaremi et al. (2012)
Singapore	Singapore Botanic Garden (Urban park)	4 distinct land covers: High density vegetation, low density urban forest, cluster of low-rise buildings and Eco-Lake (artificial water body)	Yes	Tmrt, THI, WBGT and PET	Physical, physiological and psychological	Chow et al. (2016)
	Shenton Way, Singapore's Central Business District (CBD)	Urban Street Canyon	No	PET	Physical, physiological	Yang, Nam et al. (2016); Yang, Niyogi et al. (2016); Yang, Wong et al. (2016)
	Central Business District (CBD) of Singapore and residential area of eastern Singapore	Areas with high density commercial and residential buildings, close proximity to large water body and parks	No	Tmrt	Physical	Tan et al. (2013)
	13 different outdoor urban spaces in Singapore	Typical resting places including parks, squares, streets, university campus and quay	Yes	PET	Physical, physiological and psychological	Yang et al. (2013a)
	13 different outdoor spaces in Singapore. (Exact location and site characteristic was not reported)	Typical resting places in urban Singapore	Yes	Not evaluated	Physical, psychological	Yang et al. (2013b)
	Singapore Armed Forces Military Institute (SMI)	Parade square	Yes	Not evaluated	Physical, psychological	Ann and Fang (1997)
Indonesia	Jakarta (Taman Impian Jaya Ancol, Taman Mini Indonesia Indah and Ragunan Zoo)	Shaded, sunny and half-shaded area and variating greeneries (dense, less dense and sparse dense) in 3 parks	No	PET	Physical, physiological	Koerniawan and Gao (2015)
	Mega Kuningan superblock, Jakarta	Superblock (shaded, half-shaded and open area)	No	PET	Physical, physiological	Koerniawan and Gao (2014a)
	Mega Kuningan superblock, Jakarta	Superblock (shaded, half-shaded and open area)	No	PET	Physical, physiological	Koerniawan and Gao (2014b)
Vietnam	Greater Ho Chi Minh city	Not stated	No	THI	Physical, physiological	Van Doan et al. (2016)
Thailand	Campus of Chulalongkorn University, Bangkok	Building canyon, pond side, playground, building's side bower and open space with consideration of ground surface type and sky view factor	Yes	ETFe	Physical, physiological, psychological	Kurazumi et al. (2016)
Philippines Cambodia Timor-Leste Laos Brunei Myanmar	No publications were found from these countries					

studies available in SEA.

4.1. In-situ field measurements

4.1.1. Objective field measurements

4.1.1.1. Study area selection. OTC studies is highly dependent on the microclimatic conditions of the thermal environment which is influenced by urban outdoor spaces and morphology. Hence, the selection of study area is a vital element in OTC studies. Past studies have been conducted in various urban areas representing different urban morphology such as courtyards (Bakar & Gadi, 2016), shaded outdoor spaces (Makaremi et al., 2012), boulevard streets (Din et al., 2014; Qaid et al., 2016), urban street canyons (Yang, Nam et al., 2016; Yang, Niyogi et al., 2016; Yang, Wong et al., 2016), parade squares (Ann & Fang, 1997), recreational gardens (Bakar & Gadi, 2016), lake gardens (Nasir, Ahmad, & Ahmed, 2012 , Nasir, Ahmad, & Ahmed, 2013a, Nasir, Ahmad, & Ahmed, 2013b), urban parks (Chow et al., 2016), dense low-rise and high-rise residential areas (Qaid et al., 2016), high density commercial and residential buildings (Tan, Wong, & Jusuf, 2013), superblocks (Koerniawan and Gao, 2014a, 2014b), theme parks (Koerniawan & Gao, 2015) and areas within universities (Din et al., 2014; Kurazumi et al., 2016; Makaremi et al., 2012).

Precise and detailed site reporting as shown in the work of Bakar and Gadi (2016) is indispensable for comparative studies in an urban context. In Bakar and Gadi's (2016) study, the orientation and physical built forms of four field sites representing semi-shaded, open and covered area are reported in a comprehensive and well-defined manner. Similarly, studies by Chow et al. (2016), Qaid et al. (2016), Din et al. (2014), Yang, Wong, and Zhang (2013b) and Kurazumi et al. (2016) were also among the few compendious assessments that presented extensive and detailed descriptions of the study sites.

4.1.1.2. Data collection for meteorological and urban site parameters. Various approaches have been used to collect data for OTC studies. The assessment of physical thermal environment is done via in-situ measurements to collect meteorological data and physical site data such as building morphology, aspect ratio, sky view factor (SVF) and so on. While most of these studies collected primary data, Hanipah et al. (2016), Nordin and Hassan (2015) and Van Doan et al. (2016) used secondary data which are obtained from meteorological department of their respective countries, i.e., Malaysian Meteorological Department and Hydro-Meteorological Data Centre of Vietnam.

Despite a wide range of urban morphologies covered in past OTC studies, only few studies reported physical site data such as surface materials and albedo, street/building orientation, aspect ratio, SVF and abundance of vegetation as highlighted in the work of Bakar and Gadi (2016), Chow et al. (2016), Yang et al. (2015) and Kurazumi et al. (2016). Some studies such as by Makaremi et al. (2012) selectively reported cloud cover while Tan et al. (2013) and Koerniawan and Gao (2014a, 2014b) reported SVF only in their study.

In terms of meteorological data collection, common parameters collected for OTC studies are Ta, RH, v, I, and globe temperature. The height of instrument setup is reported to be in between 0.9 to 3.0 m above ground surface to collect data representing human height level (Chow et al., 2016; Van Doan et al., 2016; Koerniawan & Gao, 2014a, 2014b; Kurazumi et al., 2016; Nasir et al., 2012, 2013a, 2013b; Qaid et al., 2016; Yang et al., 2013b; Yang et al., 2015). Besides common meteorological parameters, Bakar and Gadi (2016), Qaid et al. (2016), Tan et al. (2013), Koerniawan et al. (2014a, 2014b) and Ann and Fang (1997) also measured the surface temperature. In another study, Kurazumi et al. (2016) measured the respondent's skin temperature (head, trunk, arm, hand, thigh, lower leg and foot) and clothing value for the determination of Sensational and Physiological Climatic Environment index (ETFe). A summary of meteorological and urban site parameters reported during field measurements is exclusively presented in Table 3.

In all of the studies, point measurements of meteorological data were collected using either automated weather stations or mobile handheld instruments. Unlike other studies, Qaid et al. (2016) and Kurazumi et al. (2016) was among the few that conducted mobile survey in their study. Permanent meteorological station may provide high temporal resolution and long-term coverage of in-situ data but it couldn't provide high spatial details as moving observations could (Morris et al., 2017). A detailed measurement procedure is available in their published work. Qaid et al. (2016) conducted mobile survey method to investigate the intra-air temperature distribution in Putrajaya, Malaysia, while Kurazumi et al. (2016) investigated the thermal adaptation of the respondents in the campus of Chulalongkorn University, Thailand.

4.1.2. Subjective assessment using questionnaire

Thermal comfort is a study on the perception, sensation or acceptance towards the immediate thermal environment that involves the physiological and psychological aspects of the respondents. It is deemed to be complex because of the highly subjective psychological and behavioural influences such as thermal experience, comfort expectations, perceived thermal control, culture and duration of exposure (Hoppe, 2002; Brager & de Dear, 1998; Nikolopoulou et al., 2001; Nikolopoulou & Steemers, 2003; Parson, 2003). On top of that, behavioural responses that can be voluntarily controlled by changing posture, moving to a warmer or cooler place, turning on or turning off the HVAC system and choosing appropriate clothing can have significant impact towards the thermoregulation of the human body (Parson, 2003). As thermal comfort is highly subjective from one person to another (Epstein & Moran, 2006), on-site questionnaire surveys are needed at an individual level for the analysis of thermal comfort (Hwang & Lin, 2007). Despite its importance to express thermal comfort conditions at individual level, about half of the OTC studies in SEA did not include subjective assessment in their studies. Table 4 elaborates on the data collection period, study site and sample size reported in OTC studies in tropical SEA.

Subjective assessments of thermal comfort which are administered through survey questionnaires are usually conducted simultaneously with microclimate measurements. In Chow et al.'s (2016) study, respondents passing by within 3–5 m of the measuring station are invited to participate in the subjective assessment as it is rational to assume a consistent microclimate condition within (Spagnolo & de Dear, 2003). The time of survey is also recorded to ensure coherence with microclimatic measurements of nearby instrument. Doing so would allow comparison in between the qualitative and quantitative measures in thermal comfort studies. For example, Nasir et al. (2012) compared the Thermal Sensation Vote (TSV) with Physiological Equivalent Temperature (PET) to evaluate the thermal comfort level of Malaysians in a lake garden at Shah Alam. Similar comparisons of subjective assessment and thermal comfort indices are done in the studies of Nasir et al. (2013a and 2013b), Makaremi et al. (2012), Chow et al. (2016), Yang et al. (2013a) and Kurazumi et al. (2016).

It is worth mentioning that only two of the studies conducted in SEA by Kurazumi et al. (2016) and Yang et al. (2013b) involved respondents from other regions such as Japan and China. In a study to understand the influence of ethnicity towards thermal responses, Kurazumi et al. (2016) assessed the thermal sensation of Japanese students in Chulalongkorn University at Thailand and compared their responses with the local students. In another study, Yang et al. (2013b) conducted a collaborative study with researchers from China to compare human thermal conditions in outdoor urban spaces in between Singapore and Changsha, China. However, the discussions in this review will only be limited to the OTC assessments conducted in tropical SEA.

4.1.2.1. Data collection period for subjective evaluation of OTC. There are studies done to address the seasonal monsoon influence towards OTC in tropical SEA. For example, Kurazumi et al. (2016) addressed the rainy season in September and Chow et al. (2016) addressed the North-East

Table 3
Meteorological and urban site parameters reported during field measurements in OTC studies in the tropical context of SEA

Country	Sources	Meteorological parameters						Height of measurement (m)	Urban site parameters
		Ta (°C)	**RH (%)**	**I (W/m²)**	**v (m/s)**	**Tg (°C)**	**Other parameters**		
Malaysia	Bakar and Gadi (2016)	✓ (Dry & wet bulb temperature)	✓	-	✓	✓	Surface temperature of floor and wall, and illuminance	Not mentioned	Surface material, orientation, aspect ratio
	Hanipah et al. (2016)	✓	✓	✓	✓	✓	-	Not mentioned	N/A
	Qaid et al. (2016)	✓	✓	✓	✓	-	Surface temperature	3.0	N/A
	Jabarudin and Harith (2015)	✓	✓	-	✓	-	-	Not mentioned	N/A
	Nordin and Hassan (2015)	✓	-	-	-	-	-	Not mentioned	N/A
	Din et al. (2014)	✓	✓	✓	-	-	-	Not mentioned	N/A
	Nasir et al. (2013a)	✓	✓	-	✓	-	-	1.5	N/A
	Nasir et al. (2013b)	✓	✓	✓	✓	-	-	1.5	N/A
	Nasir et al. (2012)	✓	✓	✓	✓	-	-	1.5	N/A
	Makaremi et al. (2012)	✓	✓	-	✓	✓	Vapour pressure	Not mentioned	Cloud cover
Singapore	Chow et al. (2016)	✓	✓	✓	✓	✓	-	1.3	N/A
	Yang et al. (2015)	✓	✓	-	✓	-	Vapour pressure	2.0	Street orientation, height-to-width ratio and vegetation
	Tan et al. (2013)	✓	-	✓	✓	✓	Surface temperature	Not mentioned	Sky View Factor
	Yang et al. (2013a)	✓	✓	✓	✓	✓	Vapour pressure	1.1	N/A
	Yang et al. (2013b)	✓	✓	✓	✓	✓	-	1.1	N/A
	Ann and Fang (1997)	✓	-	✓	-	-	-	Not mentioned	N/A
Indonesia	Koerniawan and Gao (2015)	✓	✓	-	✓	-	-	Not mentioned	SVF, albedo, building and open space orientation and Green Plot Ratio
	Koerniawan and Gao (2014a)	✓	✓	-	✓	-	Surface temperature	1.5	Sky View Factor
	Koerniawan and Gao (2014b)	✓	✓	-	✓	-	Surface temperature	1.5	Sky View Factor
Vietnam	Van Doan et al. (2016)	✓	✓	-	-	-	-	2.0	N/A
Thailand	Kurazumi et al. (2016)	✓	✓	✓	✓	-	Ground and water surface temperature	0.9	SVF, ratio of green and water surface solid angles, surface albedo

Table 4
Data collection period, study site and sample size in subjective OTC assessment conducted in the tropical context of SEA

Country	Sources	Data collection period	Data collection site	Sample size (n)
Malaysia	Bakar and Gadi (2016)	Not mentioned	Courtyard (semi-shaded, open area and covered area) and recreational garden	123
	Hanipah et al. (2016)	N/A		
	Qaid et al. (2016)			
	Jabarudin and Harith (2015)	Not mentioned	Beach resorts near coastal area	50[a]
	Nordin and Hassan (2015)	N/A		
	Din et al. (2014)	Not mentioned	Boulevard street and 4 types of building layouts (in front, between, within and surrounded by the building)	79
	Nasir et al. (2013a)	Day 70, 99, 127, 134, 142 and 161 of year 2012	Lake Garden	438
	Nasir et al. (2013b)	Day 70, 99, 134 and 161 of year 2012	Lake Garden	292
	Nasir et al. (2012)	Day 70, 99, 134 and 161 of year 2012	Lake Garden	292
	Makaremi et al. (2012)	16th to 17th Mac and 7th to 8th Apr 2010	Shaded outdoor spaces	200
Singapore	Chow et al. (2016)	8th & 21 st Dec 2013, 24th & 26th Jan 2014, 25th May 2014, 7th, 8th & 15th Jun 2014	High density vegetation, low density urban forest, cluster of low-rise buildings and Eco-Lake (artificial water body)	1573
	Yang et al. (2015)	N/A		
	Tan et al. (2013)			
	Yang et al. (2013a)	Aug 2010 to May 2011	Typical resting places including parks, squares, streets, university campus and quay	2020
	Yang et al. (2013b)	Aug 2010 to May 2011	Typical resting places in urban Singapore	2036
	Ann and Fang (1997)	Mar to Jul of 1994	Parade square	325
Indonesia	Koerniawan and Gao (2015)	N/A		
	Koerniawan and Gao (2014a)			
	Koerniawan and Gao (2014b)			
Vietnam	Van Doan et al. (2016)			
Thailand	Kurazumi et al. (2016)	September (year not mentioned)	Building canyon, pond side, playground, building's side bower and open space with consideration of ground surface type and sky view factor	17

N/A indicates that these studies did not conduct subjective assessment.
[a] Related feedback out of 2468 online survey gathered.

(NE) and South-West (SW) monsoon in their respective studies. Although it is not specifically mentioned in most of the studies, the data collection period generally falls into the two distinctive monsoon seasons from November to March (NE monsoon) and May to November (SW monsoon) as shown in Table 4.

In an attempt to address the diurnal changes in climatic conditions within a day, Yang et al. (2013a) conducted surveys in four sessions, i.e., morning (0900–1100), mid-day (1200–1400), afternoon (1500–1700) and evening (2000–2200). In another study approach, Chow et al. (2016) conducted subjective measurements from 0900 to represent two hours after sunrise and until 2000 to represent one hour after sunset. On top of that, the survey was conducted during the weekends (where most site visits occur) to maximise response rate.

4.1.2.2. Sample size. Sample size is important when it comes to the generalization of outcome towards a larger population especially when the perception towards the thermal environment is highly subjective. Sample size of studies ranges from 17 individuals (Kurazumi et al., 2016) up to 2036 individuals (Yang et al., 2013a) in various selected study areas in SEA. The sample size from various studies in SEA is as shown in Table 4.

Besides that, the target population is equally important as it greatly influences the findings of the study. For example, Kurazumi et al. (2016) selected 17 healthy females (10 Thai with 7 Japanese females) to identify the influence of ethnic difference in thermal responses in a tropical urban climate. In another approach, Ann and Fang (1997) selected 325 soldiers to evaluate their thermal comfort as relate to the type of pavement for foot drills. However, most of the studies in SEA tend to randomly select the respondents from their study areas.

4.1.2.3. Scales used in OTC studies. Generally, subjective assessment uses a set of validated scales to assist a person in describing their perception towards the surrounding environment. For example, thermal sensation is described using scales ranging from “too cold” to “too hot” with neutral separating the two-ended outcomes (Epstein & Moran, 2006). Besides that, there are also scales used to describe the sensation/perception and preference towards other meteorological parameters such as humidity, wind and solar radiation. For example, Yang et al. (2013a) required the respondents to express their sensation towards the humidity, wind speed and solar radiation intensity using a 5-point scale and their respective preference using a 3-point scale. The scales identified from OTC studies in SEA for thermal sensation, thermal comfort, thermal preference and thermal acceptance is as shown in Tables 5–7 while the scales used for assessment of sensation towards humidity, wind and sun is as shown in Table 8.

In some studies, the scales for the assessment of thermal comfort is adjusted to fit local context. For example, Din et al. (2014) conducted the questionnaire survey in Putrajaya and University Technology of Malaysia using a modified ASHRAE 7-point scale (−3 very cool, −2 cold, −1 slightly cool, 0 neutral, +1 slightly warm, +2 hot, and +3 very hot) to rate thermal comfort level. The modified scale of “+2” and “+3” representing “hot” and “very hot” would better define the hot conditions in a tropical climate as compared to “+2” and “+3” representing “warm” and “hot” respectively (Din et al., 2014).

4.2. Modelling and simulation approach in OTC studies

The integration of modelling and simulation has been found to be beneficial for both UHI and OTC related studies (Ramakreshnan et al., 2018). Certain modelling software can calculate the value of OTC indices such as PET, UTCI, PMV and SET, while others that are more advanced and complex can provide forecasting in weather patterns. The software used in OTC studies in SEA is briefly presented in this section.

4.2.1. Stochastic approach applying first order Markov Chain

The work of Nordin and Hassan (2015) is distinguished from other thermal comfort studies conducted in SEA. They applied the first order of Markov Chain in their stochastic approach to model the effect of air temperature towards human thermal comfort. Markov Chain model is one of the commonly used statistical predictive model in atmospheric sciences to analyse the probabilities of an event’s occurrence based on a time-series method (Roshan & Nastos, 2018). Five years daily maximum temperature data was obtained from Malaysian Meteorological Department (MMD) for the station at Bayan Lepas for the input of the modelling. Based on the findings of Makaremi et al. (2012), Nordin and Hassan (2015) define daily maximum temperature exceeding 34 °C as hot state (above thermal comfort range) and lesser than 34 °C as normal state (within thermal comfort range). According to the 16 years dataset, their findings revealed only 2.2% of daily air temperature exceeds the thermal comfort range of 34 °C PET.

4.2.2. ENVI-Met

ENVI-Met is a three-dimensional (3D) microclimate model capable of simulating micro-scale interactions between individual buildings, surfaces, and plants (Yang, Nam et al., 2016; Yang, Niyogi et al., 2016; Yang, Wong et al., 2016) in an urban environment based on laws of fluid dynamics and thermo-dynamics (Bruse & Fleer, 1998). ENVI-Met has been widely used for many UHI and thermal comfort studies around the world. In tropical SEA, Yang, Nam et al. (2016), Yang, Niyogi et al. (2016), Yang, Wong et al. (2016), Yang et al. (2015), Qaid et al. (2016) and Koerniawan and Gao (2014a, 2014b) were among the few who simulated OTC conditions using the ENVI-Met software. Besides simulating OTC, the simulation capability of ENVI-Met is also useful to study the effect of urban design such as street design (Yang, Nam et al., 2016; Yang, Niyogi et al., 2016; Yang, Wong et al., 2016) and street aspect ratio (Yang et al., 2015) on OTC.

In the ENVI-Met model, receptors can be placed and extracted to provide point-specific microclimate variables such as T_a, RH, v and Mean Radiant Temperature (T_{mrt}) as seen in the work of Yang et al. (2015) and Qaid et al. (2016). This feature enables a comprehensive

Table 5
Scales used in thermal sensation assessment in the tropical context of SEA

Scales	Scales used to assess thermal sensation									
	ASHRAE scale		Modified ASHRAE scale		5-point thermal sensation		Bedford		Environment Canada rating
Rating score	−3	Cold	−3	Very cool			−3	Cold	
	−2	Cool	−2	Cold	−2	Cold	−2	Cool	Cold
	−1	Slightly cool	−1	Slightly cool	−1	Cool	−1	Slightly cool	Cool
	0	Neutral	0	Neutral	0	Neutral	0	Neutral	Neutral
	+1	Slightly warm	+1	Slightly warm	1	Warm	+1	Slightly warm	Warm
	+2	Warm	+2	Hot	2	Hot	+2	Warm	Hot
	+3	Hot	+3	Very hot			+3	Hot	
Studies using aforementioned scales	Chow et al. (2016); Yang et al. (2013b); Kurazumi et al. (2016)		Din et al. (2014)		Makaremi et al. (2012)		Bakar and Gadi (2016)		Nasir et al. (2012, 2013a, 2013b)

Table 6
Scales used in thermal comfort assessment in the tropical context of SEA

Scales	Scales used to assess thermal comfort									
	ASHRAE thermal comfort		Thermal comfort		Thermal comfort	Heat-related discomfort		Thermal perception on daily basis
Rating score	1	Very comfortable						
	2	Comfortable	−2	Very uncomfortable	Comfortable	1	Very uncomfortable	Discomfort
	3	Slightly comfortable	−1	Uncomfortable	Slightly uncomfortable	2		Sickness
	4	Neutral	0	Acceptable	Uncomfortable	3	Satisfactory	Less comfort
	5	Slightly uncomfortable	+1	Comfortable	Very uncomfortable	4		No effect
	6	Uncomfortable	+2	Very comfortable	Extremely uncomfortable	5	Very comfortable	
	7	Very uncomfortable						
Studies using aforementioned scales	Bakar and Gadi (2016)		Makaremi et al. (2012)		Kurazumi et al. (2016)	Ann and Fang (1997)		Din et al. (2014)

assessment of thermal comfort conditions in the study area. For example, Yang et al. (2015) extracted data from 30 points within the simulated study area for thermal comfort analysis which is equivalent to conducting 30 subjective assessment of OTC via questionnaire survey. Besides that, the simulated climatic data from ENVI-met can be used as input in other software such as the RayMan model to calculate the PET value in the study area.

The reliability of the simulated data from ENVI-Met for OTC study in SEA has been statistically validated in the work of Yang, Nam et al. (2016), Yang, Niyogi et al. (2016), Yang, Wong et al. (2016), Yang et al. (2015) and Qaid et al. (2016). Although there is negligible variance among the simulated and measured data, it is agreed that ENVI-Met is a promising research tool for OTC study in SEA. In fact, Yang, Nam et al. (2016), Yang, Niyogi et al. (2016), Yang, Wong et al. (2016) have done a meticulous validation compared to the other studies by Emmanuel, Rosenlund, and Johansson (2007), Wong, Ignatius, Eliza, Jusuf, and Samsudin (2012), Kakon, Mishima, and Kojima (2009) and Peng and Jim (2013) who had validated ENVI-Met based on only one point or one microclimatic parameter. Yang, Nam et al. (2016), Yang, Niyogi et al. (2016), Yang, Wong et al. (2016) compared few simulated microclimate data such as T_a, RH, v and T_{mrt}, with the data collected from field measurements. A detailed discussion on the ENVI-Met model evaluation and validation can be obtained from the studies of Yang, Nam et al. (2016), Yang, Niyogi et al. (2016), Yang, Wong et al. (2016) and Qaid et al. (2016).

4.2.3. Particle Image Velocimetry (Wind-tunnel simulations)

Particle Image Velocimetry (PIV) is an optical method commonly used to measure instantaneous fluid velocity and to visualize the movements of fluids (Grant, Zapata, & Middleton, 2010). Jabarudin and Harith (2015) evaluated the wind environment around two beach resorts representing the east and west coast of Peninsula Malaysia using a wind-tunnel simulation performed using PIV. It is known that wind velocity plays an important role towards the visitor's OTC at the two beach resorts. Their findings revealed that the average wind speed (range of 0.7–1.7 m/s) is sufficient for OTC based on the findings from the work of Kubota and Ahmad (2004). On top of that, sentiment analysis is used to assess the visitor's perception on environment (air) comfort from the two beach resorts. The findings from sentiment analysis corresponded well with the results from the wind-tunnel simulation. However, there are few shortcomings identified in their work. The discrepancies in their work are highlighted in Section 5.

4.2.4. Weather Research and Forecasting (WRF) Model

The WRF model is a numerical weather prediction model that can also function as a regional climate model. The WRF model has the capability to investigate the impact from land use and land cover (LULC) changes, and variations in both UHI and urban microclimate parameters (Chen et al., 2011). On top of that, WRF can estimate the surface temperatures and heat fluxes of roads, roofs and walls to express the heat energy transfer between land surface and atmosphere (Chen et al., 2011). In the tropical region of SEA, Morris et al. (2017) and Van Doan et al. (2016) used the WRF model coupled with Urban Canopy Model (UCM) to predict T_a, RH, and v which are related to thermal comfort at outdoors.

Morris et al. (2017) showed that the urbanization of Greater Kuala Lumpur, Malaysia has significantly led to an increase in air temperature at the height-levels of 2 m. However, it does not significantly affect the maximum and minimum value of thermal indices. The WRF model coupled with NOAH and UCM predicted the near surface temperature (T_{2m}), relative humidity (RH_{2m}) and wind speed (WS_{10m}) well with some negligible exceptions, i.e., T_{2m} ($R = 0.87$), RH_{2m} ($R = 0.75$) and WS_{10m} ($R = 0.58$). Although the model depends heavily on solar radiation, the biasness can be cancelled out due to a high spatial resolution of the model. Based on his findings, Morris et al. (2017) suggested that the WRF model is an appropriate simulation tool for assessment of urbanization influence towards OTC in a tropical urban environment.

4.2.5. Urban Canopy Model (UCM)

The UCM is a practical and inexpensive model (Baklanov, Ching, Grimmond, & Martilli, 2009) applied in various regions to simulate

Table 7
Scales used in thermal preference and thermal acceptance assessment in the tropical context of SEA

Scales	Scales used to assess thermal preference and thermal acceptance			
	McIntyre preference scale	Thermal preference		Thermal acceptance
Rating score		−2	Cooler	
	Warmer	−1	Slightly cooler	Acceptable
	No change	0	No change	Unacceptable
	Cooler	1	Slightly warmer	
		2	Warmer	
Studies using aforementioned scales	Chow et al. (2016); Yang et al. (2013b); Din et al. (2014)	Makaremi et al. (2012)		Chow et al. (2016); Yang et al. (2013b); Din et al. (2014)

Table 8
Scales used for the assessment of sensation/perception and preference towards humidity, wind and solar radiation in the tropical context of SEA

Scales	Scales used to assess the sensation/perception and preference assessment of humidity, wind and sun												
	Humidity sensation		Relative humidity perception	Humidity preference		Wind sensation		Beaufort wind-speed	Wind preference	Sun sensation		Sun preference	
Rating score	−2	Too dry				−2	Stale	Calm		−2	Too weak		
	−1	Dry	Dry	Less Humid		−1	Little wind	Light wind	Less	−1	Little weak	Weaker	
	0	Ok	Neutral	No change		0	Ok	Breeze	No change	0	Ok	No change	
	+1	Humid	Damp	More humid		+1	Windy	Strong breeze	Greater	+1	Little strong	Stronger	
	+2	Very humid				+2	Too much wind	Windy		+2	Too strong		
Studies using aforementioned scales	Chow et al. (2016); Yang et al. (2013b)		Nasir et al. (2012, 2013b)	Chow et al. (2016); Yang et al. (2013b)		Chow et al. (2016); Yang et al. (2013b)		Nasir et al. (2012, 2013a, 2013b)	Chow et al. (2016); Yang et al. (2013b)	Chow et al. (2016); Yang et al.(2013b)		Chow et al. (2016); Yang et al. (2013b)	

impacts of future urbanization on regional meteorological conditions (Chen et al., 2011). The climate model processes the heat budget on each urban surface as a two-dimensional urban geometry containing street canyons, rooftops, walls and road (Van Doan et al., 2016). To simulate the surface air temperature (T_{2m}) and relative humidity (RH_{2m}) in Greater Ho Chi Minh City (GHCM) of Vietnam, Van Doan et al. (2016) obtained the observatory data of T_{2m} and RH_{2m}, derived urban land-use dataset and data on energy consumption with population density from Hydro-Meteorological Data Centre of Vietnam, United States Geological Survey's (USGS) database, and General Statistics Office of Vietnam (2009) respectively. The validation of the UCM model showed good correlation for both simulated and observed data set, i.e., T_{2m} (R = 0.86 to 0.9) and RH_{2m} (R = 0.78–0.86) (Van Doan et al., 2016).

4.2.6. RayMan model

The RayMan model is a common software used for the calculation of Physiological Equivalent Temperature (PET). It calculates the radiation fluxes within the urban context based on meteorological parameters such as T_a, v, I and surrounding surfaces (Matzarakis, Rutz, & Mayer, 2010). In tropical SEA, Koerniawan and Gao (2014a, 2014b), Chow et al. (2016), Yang et al. (2015) and Yang et al. (2013b) determined the PET value in their studies using the RayMan model. Often, the RayMan model is also used along with ENVI-Met software as demonstrated in the work of Yang et al. (2015). Besides PET, the RayMan model is also capable of estimating the T_{mrt} with similar data input. Yang et al. (2013b) validated and showed that the RayMan model is capable to predict T_{mrt} accurately in Singapore ($R^2 = 0.924$) and Changsha ($R^2 = 0.905$) at the significant level of 95%.

4.3. Outdoor thermal comfort indices

A plethora of studies have been conducted to evaluate and grade thermal comfort and stress via various models and indices (Blazejczyk, Epstein, Jendritzky, Staiger, & Tinz, 2012). In general, thermal stress indices can be classified into three groups such as rational indices (according to heat balance equation), empirical indices (based on objective and subjective strain) and direct indices (based on direct measurements of environmental variables) (Blazejczyk et al., 2012). For a better understanding on the types of thermal comfort indices, the work of Epstein and Moran (2006) and de Freitas and Grigorieva (2015) is recommended as they have impressively classified thermal comfort, heat stress and human thermal climate indices that are widely used around the world.

Modern human thermal indices are developed based on the heat exchange process between the human body and environment which forms the fundamental human thermal energy balance equation (Mayer & Hoppe, 1987; Parson, 2003). The thermal indices developed should be able to be applied universally irrespective of difference in climates, regions and seasons (Jendritzky & Dear, 2009; Jendritzky, de Dear, & Havenith, 2012; Matzarakis, Mayer, & Iziomon, 1999). However, these indices and its scales are found to be restricted in its applicability when used for studies conducted at a different climate. For example, the neutral thermal comfort range of PET in central Europe is 18–23 °C (Matzarakis et al., 1999). On the contrary, the neutral thermal comfort range is proposed to be higher in sub-tropical Taiwan according to findings from a thermal sensation survey (Lin & Matzarakis, 2008). Hence, the OTC indices and their respective scales must be used cautiously to prevent inaccurate findings. Table 9 describes the common thermal climate indices used in OTC studies in SEA.

4.3.1. Universal Thermal Climate Index (UTCI)

UTCI is defined as the equivalent ambient temperature of a reference environment that causes the same physiological response of a reference person as the actual environment would imply (Blazejczyk et al., 2012). UTCI is developed based on the Fiala multi-node model of

Table 9
Description of thermal climate indices used in OTC studies in the tropical context of SEA.

Thermal climate indices	Description	Studies using aforementioned indices
UTCI	The equivalent ambient temperature of a reference environment that causes the same physiological response of a reference person as the actual environment would imply	Hanipah et al. (2016)
AT	The perceived temperature for a combination of temperature and relative humidity under normal conditions (mild wind speed, normal sea level pressure and no significant direct radiant heat source)	Nasir et al., (2012, 2013a, 2013b)
WBGT	A thermo-physiological index that is widely used to measure individual's heat stress under direct sunlight. WBGT is calculated based on air and globe temperatures, relative humidity, wind speed, sun azimuth angle and insolation in which the coefficients have been determined empirically	Chow et al. (2016)
PET	PET is the air temperature where the heat balance of the human body is balanced between two human body nodes (core and skin) under typical indoor settings equals to the complex outdoor conditions being assessed	Qaid et al. (2016); Nasir et al. (2012), Makaremi et al. (2012), Koerniawan and Gao (2015, 2014a, 2014b)
TSV	A numerical model proposed to assess outdoor thermal comfort in outdoor urban spaces by looking into a combined effect of air temperature, relative humidity, wind speed and mean radiant temperature	Yang et al. (2013a, 2013b)
THI	A measure of the reaction of the human body to a combination of heat and humidity	Din et al. (2014); Chow et al. (2016); Van Doan et al. (2016)
ETFe	ETFe is an index developed to evaluate the combined effect of sensational and physiological temperature in outdoor spaces. The five environmental factors that influence the heat balance of the human body such as the difference in body posture, air velocity, surface temperature, humidity, long- and short-wave radiation in the outdoor space is expressed into a temperature equivalent value	Kurazumi et al. (2016)
T_{mrt}	Is the uniform temperature of an imaginary enclosure in which the radiant heat transfer from the human body equals the radiant heat transfer in the actual non-uniform enclosure	Chow et al. (2016); Tan et al. (2013); Yang et al. (2013a)
HI	An index that expresses the combined effect of air temperature and relative humidity on human perceived equivalent temperature in shaded areas	Nasir et al. (2013a)

human thermoregulation with the consideration of an adaptive clothing model (Fiala, Lomas, & Stohrer, 1999) which allows UTCI to be applicable in thermal comfort studies across climates and seasons (Jendritzky et al., 2012). Due to UTCI's high complexity, and thus, high computational effort, UTCI can only be approximated using a regression formula that needs meteorological data input such as T_a, v, vapour pressure, and T_{mrt} (Jendritzky et al., 2012). In the work of Hanipah et al. (2016), calculation of UTCI revealed that the range of maximum heat stress at three locations in Malaysia (Alor Setar, Kuantan and Subang) is in between 42 °C to 52 °C indicating occurrence of "very strong heat stress" and "extreme heat stress" conditions according to UTCI scale.

4.3.2. Apparent Temperature (AT)

AT is defined as the perceived temperature for a combination of temperature and relative humidity under normal conditions (mild wind speed, normal sea level pressure and no significant direct radiant heat source) (Quayle & Doehring, 1981).

Nasir et al. (2013b) used AT as a representation of perceived outdoor air temperature calculated using the following equation:

$$AT = Ta + 0.33\,x\,e - 0.70\,x\,v - 4.00 \quad (1)$$

Where,

Ta is air temperature (°C), e water vapour pressure or humidity (hPa) and v is wind speed (ms^{-1}).

The vapour pressure, e, is calculated from the following equation:

$$e = \frac{RH}{100}\,x\,6.105\,x\,EXP(17.27\,x\,\frac{T_a}{(237.7 + Ta)}) \quad (2)$$

In another study of Nasir et al. (2013a), Heat Index (HI) was used to represent AT in °F. It is worth noting that the finding from Nasir's work shows that there is no relationship between HI and Thermal Sensation Vote (TSV) ($R^2 = 0.01035$).

4.3.3. Wet-Bulb Globe Temperature (WBGT)

The WBGT is a thermo-physiological index that is widely used to measure individual's heat stress under direct sunlight (Chow et al., 2016; Epstein & Moran, 2006). WBGT is widely used by the United States National Weather Service and United States Military for identifying levels of heat stress (Lin, Lin, & Hwang, 2013). Besides that, it is also used as an ISO standard that outlines a screening method for evaluating the presence of heat stress among the workers exposed to hot environment (ISO 7243:2017). These ISO criteria is adopted by Occupational Safety and Health Administration (OSHA) and National Institute for Occupational Safety and Health (NIOSH) to evaluate heat exposures in occupational environment.

WBGT is calculated based on air and globe temperatures, RH, v, sun azimuth angle and insolation in which the coefficients have been determined empirically. In many situations, the quantification of WBGT is unfeasible because of the difficulty in measuring the globe temperature (T_g). The equation for the calculation of WBGT directly from Kestrel 4400 (an instrument used for measuring heat stress) is as follow:

$$WBGT = 0.7T_{wb} + 0.2T_g + 0.1T_a \quad (3)$$

Where,

T_{wb}, T_g and T_a represents wet-bulb temperature, globe temperature and air temperature respectively. In the study of Chow et al. (2016), T_{wb} is derived from RH and dew-point temperatures.

4.3.4. Physiological Equivalent Temperature (PET)

PET is defined as the air temperature where the heat balance of the human body is balanced between two human body nodes (core and skin) under typical indoor settings equals to the complex outdoor conditions being assessed (Chow et al., 2016; Höppe, 1999). The physiological response of the human body towards the thermal environment is expressed as a heat-balance model according to the Munich Energy-balance Model for Individuals (MEMI) (Girgis, Elariane, Elrazik, & Abd Elrazik, 2016; Honjo, 2009; Höppe, 1999) as following:

$$M + Wo + R + C + Esk + Eres + Esw + S = 0 \quad (4)$$

Where,

M represents the metabolic heat production, Wo is the mechanical work, R is the fluxes of radiation, C is the sensible heat, Esk is the latent heat fluxes from or to the skin, Eres is the latent heat fluxes via the respiratory system, Esw is the latent heat fluxes through sweating, and S is the heat storage which is assumed to equal 0 at a steady state.

Data on T_a, RH or vapour pressure, v, T_{mrt}, human clothing and

activity level is needed for the estimation of PET using the RayMan model (Lin et al., 2010). As PET is expressed in a widely known unit, degrees Celsius (°C), it is used to establish a reference value among those who are unfamiliar with human bio-meteorological conditions such as urban planners and policy makers (Lin & Matzarakis, 2008).

A probit analysis is used to identify the preferred PET (obtained from intersection of two fitted probit lines) according to the thermal preference vote from the subjective assessment (Yang et al., 2013b). On the other hand, neutral PET is determined by analysing the relationship between TSV and PET (Yang et al., 2013b). The linear regression representing mean thermal sensation vote (MTSV) and PET for Singapore is:

$$MTSV = 0.234PET - 6.566,\ R^2 = 0.953 \quad (5)$$

The MTSV correlated strongly with PET ($R^2 = 0.953$), explaining 90% of variability in the thermal sensation votes. The neutral PET was 28.1 °C for Singapore as calculated by solving the equations for a mean sensation vote of zero (Yang et al., 2013b).

4.3.5. Thermal Sensation Vote (TSV)

Yang et al. (2013b) has proposed a TSV index for the OTC analysis based on a large-scale survey conducted involving more than 2000 respondents in 13 different outdoor urban spaces in Singapore. The equation is as follows:

$$TSV = 0.398T_a + 0.023RH - 0.329v + 0.038T_{mrt} - 14.061,\ R^2 = 0.801 \quad (6)$$

Where,

T_a is air temperature, RH is relative humidity, v is wind speed and T_{mrt} is mean radiant temperature.

The TSV model is also adapted in the work of Ignatius et al. (2015) to assess the OTC from the influence of outdoor air temperature and wind impact. As indicated by the equation of TSV above, any increase in T_a, RH and T_{mrt} will make subjects feel warmer whereas any increase in wind speed will make subjects feel cooler (Yang et al., 2013b).

4.3.6. Discomfort Index or Temperature-Humidity Index (THI)

Thomson's Discomfort Index (DI) is used to measure the level of human discomfort in the study of Din et al. (2014). The human discomfort level is assessed based on ambient air temperature and relative humidity. The equation for DI is expressed in the following:

$$DI = T - 0.55(1 - 0.01RH)(T - 14.5) \quad (7)$$

Where,

T is the air temperature (°C) and RH is relative humidity (%).

DI was found to be highly correlated with effective temperature (ET) index (Sohar, Tennenbaum, & Robinson, 1962) and WBGT (Epstein & Moran, 2006). Van Doan et al. (2016) used the THI developed by (Thom, 1959) and modified by (Nieuwolt, 1977) for the assessment of thermal sensation of the people in Vietnam. The equation for the THI is presented as follow:

$$THI = 0.8T_a + \frac{RH*T_a}{500} \quad (8)$$

Where,

T_a is air temperature (°C) and RH is relative humidity (%).

The comfort limits are defined as:

- 100% of subjects felt comfortable when 21 ≤ THI ≤24,
- 50% of subjects felt comfortable when 24 ≤ THI ≤26, and,
- 100% of subjects felt uncomfortably hot when THI > 26

THI is also used in the study of Chow et al. (2016) for the assessment of OTC in Singapore. THI is often criticized as it doesn't account for the variation of wind speed, a known climatic factor which greatly influence the OTC particularly in the hot and humid region. Through their study in Malaysia, Din et al. (2014) had suggested to increase the "uncomfortable" range to > 30.1 °C (Chow et al., 2016) as THI comfort range for temperate climate is practically inapplicable in the context of tropical hot and humid region.

4.3.7. Sensational and Physiological Climatic Environment index (ETFe)

ETFe is an index developed to evaluate the combined effect of sensational and physiological temperature in outdoor spaces which considers the change in posture, air velocity, long-wave and short-wave solar radiation, contact material surface temperature and humidity into a temperature-equivalent value measured in Kelvin (K) (Kurazumi et al., 2016). The five environmental factors that influence the heat balance of the human body in the outdoor space is expressed as follows:

$$ETFe = T_a + \frac{TVF_{hta}}{h_{fL}} + \frac{ERF_{htaL}}{h_{fL}} + \frac{ECF_{hta}}{h_{fL}} + \frac{EHF_{ETFe}}{h_{fL}} + \frac{ERF_{htaS}}{h_{fL}} \quad (9)$$

Where,

ETFe is the enhanced conduction-corrected modified effective temperature (K); Ta is air temperature (K); TVF_{hta} is the convective heat transfer area of the combined thermal velocity field (W/m^2); ERF_{htaL} is the radiant heat transfer area combined effective radiation field concerning long-wave radiation in outdoor space (W/m^2); ECF_{hta} is the heat transfer area combined effective conduction field (W/m^2); EHF_{ETFe} is the effective humid field at enhanced conduction-corrected modified effective temperature (W/m^2); ERF_{htaS} is the radiant heat transfer area combined effective radiation field concerning short-wave solar radiation in outdoor space (W/m^2); and hfL is the sensible heat transfer coefficient in outdoor space (W/m^2 K).

4.3.8. Mean Radiant Temperature (T_{mrt})

As defined according to ASHRAE, T_{mrt} is the uniform temperature of an imaginary enclosure in which the radiant heat transfer from the human body equals the radiant heat transfer in the actual non-uniform enclosure. In other words, T_{mrt} is also the summation of all short-wave and long-wave radiation fluxes that influence the people's thermal comfort especially in an urban outdoor setting (Emmanuel, 2005). In the study of Chow et al. (2016), the equation as proposed by Thorsson, Lindberg, Eliasson, and Holmer (2007) is used to estimate T_{mrt}. The equation is expressed as follow:

$$T_{mrt} = [(T_g + 273.14)^4 + \frac{(1.10*10^8 V_a^{0.6})}{\varepsilon D^{0.4}}*(T_g - T_a)]^{0.25} - 273.15(°C) \quad (10)$$

Where,

T_g is globe temperature (°C), T_a is air temperature (°C), V_a is air velocity (m/s), D is globe thermometer (m) and ε is emissivity.

In OTC study, the accurate estimation of solar radiation expressed as T_{mrt} is very important (Ndetto & Matzarakis, 2017) especially in a tropical urban city characterized with high solar radiation throughout the year. The most accurate method to estimate T_{mrt} is the six-direction method using radiometers but is deemed impractical as it is costly and complex (Thorsson et al., 2007). As so, many thermal comfort studies relied on the globe temperature estimation method due to its convenience, portability and affordability. In the work of Tan et al. (2013), customized globe thermometers are used for large-scale estimation of T_{mrt} in Singapore. A detailed description of the customization and validation of the globe temperature was presented in the published work of Tan et al. (2013).

5. Methodological discrepancies and shortcomings in OTC studies in tropical SEA

5.1. Poor reporting of study area location, site characteristic and data source

The OTC level of a person is directly influence by surrounding

microclimate conditions. Hence, in any given OTC studies, the reporting of study area location, especially its site characteristics becomes crucially important. On top of that, attention must also be given to proper data source reporting to ensure coherence in OTC studies.

5.1.1. Poor choice of study area

The credibility of an OTC study is affected by the choice of study area. For example, Hanipah et al. (2016) calculated maximum heat stress occurrence using meteorological data from a weather station located next to an airport in Subang, Malaysia. The recorded values may be interfered by airplane's movements in and out of the airport. In this case, the highest reported UTCI value (49.7 °C) for Subang from a 20 years dataset becomes ambiguous.

Besides that, the selection of study area is also crucial to generalize authentic results for a bigger population. In their study, Nasir et al. (2013a, 2013b) conducted interview sessions with park users near to the children's playground. The respondents are mainly reported to be sitting before the interview session while very few are running or exercising prior to the study. The chosen study area may have led to unintentional sampling bias excluding other active park users. Therefore, their findings which highlighted a significant relationship between human thermal comfort and preference of activity is debatable.

From another study, Din et al. (2014) validated the thermal sensation results in Putrajaya using findings from interview sessions conducted at University Technology of Malaysia (UTM), which is located about 30 km away. Although Putrajaya and UTM shares the same tropical climate and sub-urban properties, the thermal environment in these two study areas may not be the same. Hence, the validation of thermal sensation results in Putrajaya becomes ambiguous to explain the thermal environment in UTM. While 79 respondents are involved in the study at Putrajaya, the significance level are not reported. Consequently, their newly proposed range of DI for tropical countries is doubtful and clearly needs further studies to prove its applicability.

5.1.2. Poor site reporting

A majority of the studies conducted in SEA overlooked the importance of site reporting. For example, Koerniawan and Gao (2014a, 2014b) determined the OTC levels in 8 locations (representing shaded, half-shaded and open areas) within Mega Kuningan superblock at Jakarta, Indonesia. In the published article, they failed to illustrate the points of field measurements and to describe the study sites where the measurements are conducted. Proper site reporting is a pre-requisite for a good quality research paper besides facilitating knowledge dissemination among other peer researchers.

5.1.3. Poor data source reporting

Nordin and Hassan (2015) reported in the article's methodology section that a 14 years of daily maximum temperature data is used in the analysis. However, in another section of the article, it was stated that only 5 years data were obtained from the MMD in Bayan Lepas. The inconsistency in data reporting questions the reliability of findings reported from their study.

5.2. Discrepancies in subjective assessments

5.2.1. Misinterpretation of findings due to inaccurate scales used in OTC studies

Parson (2003) suggested that it is important to consider the use of language and scales in thermal comfort assessment especially when descriptors such as "neutral" comfort sensation can be expressed differently in two parts of the world due to local climate acclimatization. Hence, the thermal sensation scales from Environment Canada rating may not be entirely applicable to classify the AT in the work of Nasir et al. (2013b) in Malaysia. According to the Environment Canada rating, 29–39 °C is regarded as warm. In a tropical climate region where people are exposed to high temperature all year-round, this temperature range can be considered as "neutral" due to their adaptive thermal comfort behaviour. This may be the explanation for the distinctive results of thermal comfort indices and subjective assessment in Nasir et al. (2013b).

5.2.2. Wrong application of scales in thermal comfort studies

Bakar and Gadi (2016) used a different ASHRAE scales in their study as compared to the ASHRAE scales in other studies (refer Tables 5 and 6). ASHRAE scales are characterised with range of +3 (Hot) to −3 (Cold) representing two ends of thermal sensation. With Bedford comfort scale having the range of 1 to 7, it is suspected that Bakar and Gadi (2016) mistook the Bedford scale as ASHRAE scale in their study. Wrong application of scales in OTC studies affects the interpretation of overall findings in a study.

5.2.3. Poor selection of scales to express thermal comfort

Good selection of scales in OTC studies is important to allow comparative studies involving different areas and climate zones. For example, in Jabarudin and Harith's (2015) work, the scales chosen (categorized as positive and negative reviews) is too generic to describe thermal comfort. Similarly, the ratings indicating preference towards pavement types in Ann and Fang's (1997) study also limits comparative studies with other OTC studies.

5.2.4. Inauthenticity of online feedbacks

Among all subjective assessment conducted, only Jabarudin and Harith (2015) collected data from online review websites where merely 50 from the 2468 feedbacks are included for an analysis. The authenticity of online feedbacks is highly doubtful as feedbacks which are not collected immediately may contribute biasness to the analysis. Not only that, thermal perception is also highly influenced by individuals' past experience. The thermal perception of a person may differ from others even though is exposed to the same thermal environment. Online reviews have the tendency to miss out important factors such as individual expectation and past experience which greatly influence the thermal comfort assessments.

5.3. Biasness in OTC studies due to influence of adaptive thermal comfort behaviour

OTC studies can be subjected to bias because of the influence from adaptive behaviour in thermal comfort. For instance, an occupant from a cold air-conditioned room may find warmer environments to be comfortable. In this context, the instantaneous change in warmer thermal environment is welcomed and may lead to thermal comfort instead. Similarly, the park visitors interviewed by Nasir et al. (2013a, 2013b) may have their expectations towards the thermal environment of the lake garden prior to their visits. On top of that, each interview session only lasted for 5 min in average. Consequently, a person that just finished exercising may give very different answers on their thermal perceptions as compared to a person that just arrived to the park or those who are resting or sitting. Proper precautions must be taken to eliminate or minimize the influence of such adaptive behaviours in OTC studies.

5.4. Incompetency of a single meteorological parameter to represent OTC levels

Studies which depends on air temperature as the only indicator is insufficient to assess thermal comfort in an urban outdoor space (Chow et al., 2016). Similarly, accounting only on one parameter such as wind velocity in Jabarudin and Harith's (2015) study might not be enough to determine the thermal comfort of visitors in the study area. Besides that, a common problem related to expressing OTC as a whole is the unavailability of data such as global radiation, human metabolic rate and the clothing value. Data such as global radiation is difficult to

obtain because of its complexity in measurements. As an alternative, OTC researchers will look into other OTC indices (AT, THI, etc.) that only requires common sets of inputs such as T_a and RH. As a reminder, researchers should be well aware of the limitation in OTC indices and take extra precaution towards the assumptions in their findings.

5.5. Misconception of air temperature as thermal climate indices

The misconception of air temperature as thermal climate indices is a serious offence. In their study, Nordin and Hassan (2015) defined daily maximum temperature exceeding 34 °C as hot state (above thermal comfort range) and lesser than 34 °C as normal state (within thermal comfort range). Their findings revealed that only 2.2% of daily temperature exceeds the thermal comfort range of PET = 34 °C. It must be emphasized that daily maximum temperature is not the same as PET. Daily maximum temperature refers to the T_a measured, while, PET is a thermal index based on a 2-node thermoregulation model (Chen & Matzarakis, 2014). Although both are reported in degrees Celsius (°C), they are very much different from one another and unless assumptions are clearly stated, solely implying that T_a alone determines thermal comfort is misleading. In the context of thermal comfort, it can be reasonable to specify the level of thermal comfort based on T_a, given that proper assumptions were made, i.e., the T_{mrt} equals to T_a, the air movement is still with 50% RH and people in the environment is conducting light activity wearing normal clothing (Parson, 2003).

5.6. Lacking of validation in OTC research

The technological advancement today has encouraged the use of modelling and simulation tools in various field of research. However, the findings from modelling or simulation approach without proper validation would be meaningless and unreliable. For example, the accuracy of simulated PET value from Koerniawan and Gao (2014a, 2014b) study remains debatable since no validation was done.

Another form of validation often overlooked is the coherence of results from simulated and actual thermal sensation of respondents. The inconsistency in between the objective and subjective measurement is a known flaw among OTC studies because of the complexity of bio-meteorological interaction (Nikolopoulou & Steemers, 2003). In many cases, the subjective response doesn't coincide with measured value of thermal comfort indices. For example, findings from Nasir et al. (2012) estimated that about 90% of respondents should feel warm according to the AT value, but results from interview shows only about 20% felt warm while majority of the respondents felt neutral. Chow et al. (2016), Din et al. (2014) and Nasir et al. (2013a, 2013b) also reported similar differences in their study.

5.7. Limitation of existing microclimate and OTC simulation tools

Rather than claiming it as a discrepancy, the limitations of all modelling and simulation approaches depend profoundly on two matters. Firstly, the limitations in software's data processing ability. For example, the limitation in domain size is one of the shortcomings in Computational Fluid Dynamic (CFD) models such as ENVI-met (Mirzaei, 2015). To reduce computational cost, the domain is limited to few hundred meters given that the grid size from the X, Y and Z plane is not compromised. Another example of limitation in data processing is the inability of Urban Canopy Models (UCMs) to show airflow around the buildings which is essential for OTC studies (Mirzaei, 2015). The limitation of each software has to be understood prior to any simulation or modelling work to prevent unreliable findings.

Secondly, the limitation in data input to drive the simulation model. For example, the inability to control hourly solar radiation input in ENVI-met would affect the simulated thermal environment for OTC studies (Liu, Zheng, & Zhao, 2018). Besides that, the authenticity of data input also plays a major role in ensuring reliable, accurate and representative findings from any simulation or models. Minimizing systematic error or random error could be the best ways to improve reliability of findings from simulation results.

6. Holistic approach for future OTC studies in tropical SEA

In this particular section, a holistic approach is suggested to improve the coherence and reliability of future OTC studies based on the methodological discrepancies highlighted in Section 5.

6.1. Location and site characteristic reporting

Physical site characteristics such as horizontal surface cover (type of land-use, pavement type, etc.) and vertical structure (buildings, artificial structures, trees, etc.) have strong influence towards the variations in microclimate conditions and OTC level from one urban outdoor space to another. Hence, the location and site characteristic reporting must be in a well-defined way to ensure proper and reliable dissemination of research findings. A good example of well-defined site description is shown in the work of Chow et al. (2016). While there are no specific site reporting formats for OTC studies, Stewart and Oke's 'Local Climate Zones' (LCZ) site classification system can be referred instead. As the study of OTC and UHI is inter-related, UHI's method of site reporting can be adapted to ensure better communication of findings in OTC studies. Site reporting according to LCZ is believed to be a refined approach allowing clear description of physical site properties involving various urban morphologies (Oke & Stewart, 2012; Ramakreshnan et al., 2018). The consistency in site reporting is very important and must be practiced by researchers from the same field to allow comparative study across different regions and climates.

6.2. Experimental setup for meteorological measurements

Meteorological measurements are pre-requisite to any OTC studies as it defines the thermal environment. Prior to any microscale climate observation, the study area should be well defined. A minimum radius of 200–500 m is needed for the T_a to adjust to the underlying surface forming an internal boundary layer that does not overlap with neighbouring thermal climate zones (Oke & Stewart, 2012). In fact, the distance of 100 m is considered appropriate to represent a stable microclimate condition (Oke, 2006) as seen in the work of Chow et al. (2016).

While there are no restrictions to the type of instruments used for meteorological data collection, attention must be given to the height in which measurements are collected. The instrument must be set at a distance from the ground to represent the average height of adult's centre of gravity (Mayer & Hoppe, 1987), i.e., between 1.1 to 1.5 m above ground. Besides determining the height of instrument, rainy days shall be avoided too as they may significantly influence the thermal environment and subsequently, the OTC levels. A good practice worth mentioning is by Nasir et al. (2013a), where they referred to weather forecast to avoid rainy days prior to conducting measurements.

On the other hand, Fanger (1970) suggested any study on thermal stress should explore the six fundamental factors that determines the human thermal environment, such as environmental factors (ambient T_a, T_{mrt}, RH and v) and behavioural factors (metabolic rate and clothing) (Epstein & Moran, 2006; Fanger, 1970; Parson, 2003; Vescovi, 2013). In terms of clothing and metabolic rate, it is found that the average clothing value is 0.30 clo (1 clo = 0.155 °C) while metabolic rate was assumed to be 1.2 met and 1.4 met for sitting and standing respectively (1 met = 58.15 W/m^2) (Yang et al., 2013a). Unless it is proven that the clothing value and metabolic rate for the other respondents in this tropical region of SEA to be significantly different, the findings from Yang et al. (2013a) can be adapted for the calculation of thermal comfort indices such as PET.

6.3. Objective assessment using OTC indices

Since existing thermal comfort indices vary widely, it is difficult to decide which is the most representative index. Similarly, it is also difficult to recommend one specific index for OTC studies in SEA or other regions in the world. In fact, some of the indices show strong correlation with one another. For example, UTCI correlated very well with indices such as PET, ET, SET and PMV (Blazejczyk et al., 2012). PET is identified as the most commonly used OTC index in the tropical context of SEA. Besides PET, future studies can attempt to assess other indices such as UTCI, mPET, ET and other OTC indices in various urban outdoor settings.

6.4. Subjective assessment

Due to the complexity of thermal comfort involving the unpredictable aspects of physiological and psychological response of a person, the heat balance of the human body (although it is well-developed based on extensive knowledge in human physiology and heat transfer theory) cannot fully explains the thermal perceptions and preferences in different urban outdoor environments (Hoppe, 2002; Nikolopoulou et al., 2001). Hence, subjective assessment is important not only as a validation measure for OTC indices but is also important to explore underlying issues that cannot be reflected through the indices.

The subjective assessment has to be carefully planned prior to the conduct of any study to avoid biasedness and ensuring representative results for the generalization to a larger population. First of all, the selection of sampling population is important depending on the objectives of research. For example, to understand the thermal perception of general public in outdoors Chow et al. (2016) followed the protocols from Cheng, Ng, Chan, and Givoni (2012) to minimise potential age and gender bias in the sampling. Similarly, Yang et al. (2013b) set exclusion criteria to filter respondents that are younger than 20 years old and above 60 years old in their study. Unlike studies conducted to comprehend general public response, Makaremi et al. (2012) and Kurazumi et al. (2016) focused on university students while, Nasir et al. (2012, 2013a, 2013b) focused on visitors in an urban park. Again, the selection of sampling population greatly depends on the aim of study. However, statistical measures should be carried out to determine the sampling adequacy to ensure statistically significant results.

Besides that, it is also important to use the correct scales in subjective assessment for OTC studies. The respondents in the study area can be engaged to identify their manner of expressing thermal sensation through dialogue or discussion (Parson, 2003) and survey questionnaire (Lin & Matzarakis, 2008). The findings would be beneficial to modify the thermal sensation scales to fit local context as it is done by Lin and Matzarakis (2008) in sub-tropical Taiwan and Din et al. (2014) in tropical Malaysia. On a side note, it is important to highlight the difference in between sensation and preference because sensation refers to the immediate influence of climatic parameters on the individual while the latter refers to the desired conditions or expectation on how the climatic parameters should be (Makaremi et al., 2012).

It is also highly recommended that subjective assessment needs to be done on-site and instantaneously to fully apprehend the thermal response towards the surrounding thermal environment. In terms of OTC data analysis, it is suggested that the percentage of respondents thermally accepts an environment (do not express dissatisfaction) is lowered to 70% in a dynamic outdoor environment as compared to the 80% as outlined in ASHRAE 55 (Bakar & Gadi, 2016). The 70% as suggested is reasonable to account for the microclimate fluctuations in the outdoor environment and yet it is able to represent the majority by covering more than two-third of total occupants (Bakar & Gadi, 2016). In a tropical region, lowering the percentage of thermal acceptance is justified as people from this region are more adapted to the hot-humid climate all year round.

6.5. Adaptive thermal comfort

Adaptation is practiced (either consciously or subconsciously) at individual level as an alternative to mitigation measures towards the hot and humid outdoor environments. The adaptation to thermal comfort can either be a physical and/or physiological process (Huizenga, Hui, & Arens, 2001; Sanesi, Lafortezza, Bonnes, & Carrus, 2006) distinguished according to three categories, i.e., behavioural (personal, environmental, technological or cultural), physiological (genetic adaptation or acclimatization) and psychological (habituation and expectation) (Brager & de Dear, 1998; Yang et al., 2013a). Besides that, thermal environment history which comprises of cultural background, past experience, expectation of thermal environment, active body heat control and exposure time can also directly influence the adaptation of a person towards the thermal environment (Kurazumi et al., 2016).

The inconsistency in between the objective and subjective measurements is observed in many OTC studies because of the complex biometeorology interaction (Nikolopoulou & Steemers, 2003; Makaremi et al., 2012). A respondent shows trait of adaptive thermal comfort when they perceived the environment to be better as compared to measured microclimate conditions (Nasir et al., 2012). For example, findings from Yang et al. (2013b) revealed that the respondent's preferred temperature is 25.2 °C although they felt comfortable at 28.1 °C. In a field survey conducted in Singapore, the vote of thermal acceptability and overall comfort condition contradicts with reported high values for THI and WBGT which exceeds thresholds (Chow et al., 2016). The findings from Yang et al. (2013b) and Chow et al. (2016) indicates that the difference in objective and subjective assessment may be explained by thermal adaptation.

To avoid or minimize the influence of thermal adaptation, the methodology of Kurazumi et al. (2016) is recommended. The respondents were exposed to the thermal environment for 10 min in a standing posture to allow thermal equilibrium in between the individual and thermal environment prior to conducting subjective assessment. Although the downside of carrying out such measures is tedious, it is recommended for future OTC studies to allow the heat exchange to reach a stable state before conducting subjective assessment. Despite the attempt to deal with the influence of thermal adaptation on thermal sensation, the relatively small sample number ($n = 17$) in Kurazumi et al. (2016) work suggests that for future studies involving larger samples to retest the significance of their findings.

Besides that, questions regarding respondent's previous activity before the interview can also be asked to identify the influence of metabolic rate on thermal sensation (Nasir et al., 2013a). In terms of data analysis, the impact of thermal adaptation on thermal sensation votes can be statistically tested based on purpose of stay, time of exposure, previous environment (air-conditioned or naturally ventilated), visiting frequency and adaptive behaviour through non-parametric approach as conducted in the work of Yang et al. (2013a). Similar analysis could be replicated in future OTC studies for comparative purposes.

The influence of thermal adaptation has been highlighted in various study but the influencing factors are yet to be fully understood. Such in-depth knowledge is still lacking in the tropical countries of SEA. Future OTC studies should aim to investigate the complexity of thermal adaptation and the factors influencing it.

6.6. Validation of results

Validation is important to ensure reliability of findings especially when it comes to simulation and modelling approaches. Commonly, simulated results from software like ENVI-met can be validated using observatory data. Future simulation or modelling approaches is suggested to identify and report the acceptable range of simulated results as been done by Yang, Nam et al. (2016), Yang, Niyogi et al. (2016),

Yang, Wong et al. (2016) and Qaid et al. (2016).

On top of that, validation is also needed to ensure the coherence of results from simulated and actual thermal sensation of respondents. It is recommended that comparison in between qualitative and quantitative measures is made to ensure consistency of findings among OTC studies. Correlation analysis can be done by comparing both sets of objective (microclimatic data from measuring instrument) and subjective (sensation, preference, acceptance and comfort votes from survey conducted) data. The subjective assessment will be beneficial to validate the application of various thermal comfort indices in different urban thermal environment (Ndetto & Matzarakis, 2017) besides providing adjustment to the scales to fit local context.

6.7. Influence of ethnicity difference on thermal response

The knowledge is limited regarding the influence of ethnicity towards thermal sensation especially in SEA where countries such as Malaysia, Singapore and Indonesia are known to be multi-ethnic. The only study to examine the influence of ethnicity difference on thermal responses is done by Kurazumi et al. (2016) in between Thai and Japanese respondents in a tropical urban climate. The variations in thermal responses among different ethnics in the same thermal environment can be further explored in future research. This is important to understand how people are adapting to the changing climate and how the prevailing climatic condition is affecting the temperature range tolerable by the people to feel comfort outdoors (Givoni et al., 2003).

6.8. Temporal variation of OTC (seasonal and diurnal approach)

The temporal variation in OTC study is poorly highlighted through research work due to the lack of a standardized approach. Despite having two distinctive monsoon seasons (South-West (SW) and North-East (NE) monsoon) in SEA, a majority of the studies did not account for its influences towards OTC levels. Seasonal monsoon has direct influence towards the variation in wind movement which is important for the forecasting of OTC (Hanipah et al., 2016). Roth and Chow (2012) found that the UHI intensity is higher during the SW monsoon in Singapore indicating that the T_a is different across the monsoon seasons. From another study, Chow et al. (2016) reported significantly different ($p < 0.05$) hourly T_a, v and shortwave radiation across two monsoonal seasons and highlighted the possible influence towards OTC levels in a tropical urban city (Chow et al., 2016). Although Koerniawan and Gao (2014a, 2014b) found that the thermal comfort conditions in Indonesia are the same in both February (rainy season) and October (dry season), their results are debatable as they were not statistically tested. More studies should be conducted to explore the influence of seasonal variation on OTC in tropical SEA.

Besides that, future work could also be dedicated to explore the OTC conditions in a diurnal manner as UHI intensities are reported to be highest few hours after sunset (Ramakreshnan et al., 2019). It is important that daily or yearly OTC distribution to be understood for the better planning of adaptation and mitigation strategies. The knowledge on tolerable OTC levels and urban bio-climate would contribute significantly to a better urban development (Eliasson, 2000; Grimmond et al., 2010).

6.9. Spatial variation of OTC (via mobile traverse monitoring)

Mobile traverse approach is a method for monitoring air temperature covering a huge area of the city. This approach is commonly used in UHI studies as seen in the work of Qaid et al. (2016). However, such monitoring method is restricted in terms of providing a synchronized observation despite offering high spatial coverage. Future studies can be carried out to identify the spatial distribution of OTC in a study area. This could be the preliminary step in producing heat maps representing heat stress in a geo-localized manner. Ultimately, such studies may contribute to the fundamental development of a heat-stress early warning system.

6.10. Development of a user-friendly simulation tool for microclimate and OTC studies

Existing simulation tools such as ENVI-Met and UCMs are proven useful for microclimate and OTC studies. However, the development of a new software or an update to the existing software is suggested to tackle complex issues such as limited customisation on default settings and the limited integration of input/output with other databases. Often, the end-users of these simulation tools may not have the expertise in understanding computer programming language such as C++ or python. Hence, the tools must be user-friendly in a way that it can be used by people from various background. In addition, customisation to the default settings should be allowed in software. A good example is seen in ENVI-Met where users are allowed to add new vegetation profile on top of the existing ones. Besides that, simulation tools must allow seamless integration of input/output from other available databases. For example, the time needed to map the study area can be significantly reduced if Keyhole Mark-up Language (KML) files can be used directly from sources like Google Earth to develop the study area in software. Last but not least, the software should be open-source. This would encourage more public communities to explore and provide feedbacks for their continuous improvements.

6.11. A heat stress reporting guideline for countries in tropical SEA

The occurrence of heat stress is one of the findings commonly emphasized in OTC studies as it directly affects the well-being of urban communities. Van Doan et al. (2016) used the maximum and minimum daily air temperature to determine “extremely hot day”, “hot day” and “hot night” according to the guidance from Japan Meteorological Agency for summer as there are no similar indicators for Vietnam. Similarly, there are no established heat stress indicators for other countries in the SEA region. Hanipah et al. (2016) reported time and date specific UTCI value to show the worst heat stress occurrence within two selected periods from 1994 to 2014 and from 2012 to 2014. As only worst cases are highlighted over the two periods, the trends of thermal comfort conditions are unknown. In fact, worst heat stress cases may also be outliers which does not reflect the norm of OTC conditions in study area. Rather than claiming it as a discrepancy, it is suggested that the frequency of such heat stress cases could be reported to give better indication of OTC conditions compared to reporting very specific occurrence of heat stress cases. It would be meaningful if future studies could develop a heat stress indicator which is applicable across the tropical region.

6.12. Health issues related to the outdoor thermal environment

In a review, Ramakreshnan et al. (2017) highlighted the evidence of physical and psychological health impacts of haze in ASEAN countries. Unlike health issues due to transboundary haze, the relationship between health issue and urban outdoor thermal environment in SEA or among ASEAN countries has remains unexplored. Not only that, there were no studies done to address sensitive groups such as children, the elderly, pregnant women, those with existing health problems, and those whom are constantly exposed to the outdoor environment. The assessment of health issues that arise due to outdoor thermal environment need to be considered in future research, especially in the context of tropical climate. On top of that, future studies should consider thermal response of subject-specific respondents in an urban outdoor area.

6.13. Mitigation strategies for the improvement of OTC

As the study of OTC and UHI is inter-related, mitigation measures in UHI can indirectly influence thermal comfort in outdoors too. From several studies, solar radiation is known to have the most significant effect on human thermal comfort at outdoor spaces (Bakar & Gadi, 2016; Qaid et al., 2016; Yang et al., 2013a). Besides solar radiation, wind activity which facilitates evaporation (heat transfer from the human body to the environment through sweating mechanism) is important too in improving OTC levels in the tropical climates. Future studies could emphasize on addressing these parameters at human height level to ameliorate impact of heat stress in tropical urban outdoors. Simulation approaches using software such as ENVI-Met is proven to be a reliable tool to evaluate the influence of urban design and greening towards OTC levels in the urban outdoor spaces. Future studies can also explore other modelling tools to better understand OTC in urban outdoors.

7. Conclusion: the past, the present and the future

This study critically reviews methodological caveats of OTC studies in tropical SEA. Obviously, there is a clear lacking of coherence from one study to another as highlighted in Section 5. The poor reporting of study locations, site characteristics and unreliable data source indicate a need for a holistic approach to improve the consistency of data reporting procedures. Besides that, various discrepancies are identified with the subjective assessment of OTC such as poor or wrong choice of sensation scales used to express thermal comfort, unauthentic online data collection methods and misinterpretation of results due to biasness caused by adaptive behaviour. On top of that, it is also clear that the understanding of OTC is still poor among some researchers where air temperature alone is assumed to be sufficient to express OTC. In worst cases, air temperature is assumed to be the same as PET without proper clarifications. In addition, some findings from simulation or modelling approaches remain ambiguous as the results are not validated.

Despite these methodological caveats, the current review has proposed a holistic approach for future OTC assessments in the tropical region of SEA. In Section 6, various measures were proposed to overcome the discrepancies highlighted in this study. For example, the LCZ scheme was proposed as a guideline to encourage a systematic site characterisation. Besides that, reliable experimental setups in OTC studies such as proper study area coverage, height of meteorological data measurements, standard metabolic rate and clothing value (clo value) are also suggested as references for future OTC studies. In addition, experimental controls are also recommended to minimize the influence of adaptive thermal comfort behaviour.

As a closing remark, there is still a tremendous amount of work and research that needs to be done to fill the existing knowledge gap of OTC in the tropical region of SEA. Limited peer-reviewed articles in this region highlight an urgent need for more scholarly studies to be conducted. Among some of the highlights for future directions are to explore the influence of ethnic difference towards thermal response and to investigate the spatial and temporal variation of OTC levels. Moreover, the development of a more effective and user-friendly simulation tool is also required on top of existing software such as ENVI-met. Given the impact on health (both physical and psychological) and well-being of the public, attention must be given to understand thermal comfort conditions more comprehensively in urban outdoor settings. Future studies should also look into the development of a heat stress reporting guideline to facilitate mitigation strategies for a more resilient and adaptive urban community. The holistic approach proposed through this appraisal will be beneficial to improve the reliability of findings of future OTC studies in the tropical context of SEA.

Declaration of interest

None.

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References

Acero, J. A., Arrizabalaga, J., Kupski, S., & Katzschner, L. (2013). Urban heat island in a coastal urban area in northern Spain. *Theoretical and Applied Climatology, 113*(1–2), 137–154. https://doi.org/10.1007/s00704-012-0774-z.

Ahmed, K. S. (2003). Comfort in urban spaces: Defining the boundaries of outdoor thermal comfort for the tropical urban environments. *Energy and Buildings, 35*, 103–110. https://doi.org/10.1016/s0378-7788(02)00085-3 Elsevier.

Ali Zifan (2016). *File: Southeast Asia map of Köppen climate classification.svg – Wikimedia Commons.* Retrieved January 8, 2018, fromhttps://commons.wikimedia.org/wiki/File:Southeast_Asia_map_of_Köppen_climate_classification.svg.

Ali-Toudert, F., Djenane, M., Bensalem, R., & Mayer, H. (2005). Outdoor thermal comfort in the old desert city of Beni-Isguen, Algeria. *Climate Research, 28*(3), 243–256. https://doi.org/10.3354/cr028243.

Ann, T. S., & Fang, F. T. (1997). Pavement evaluation for thermal/glare comfort during footdrills. *Building and Environment, 32*(3), 257–269. https://doi.org/10.1016/S0360-1323(96)00056-X.

ANSI/ASHRAE 55 (2013). *ASHRAE Standard 55: Thermal Environmental Conditions for Human Occupancy.* American Society of Heating, Refrigeration and Air Conditioning Engineers, ASHRAE Sta58.

Aziz, A., Ahmad, A., & Nordin, T. (2011). Flats outdoor space as a vital social place. *Asian Journal of Environment-Behaviour Studies, 3*(7), 13–24 Retrieved from https://aje-bs.e-iph.co.uk/index.php/ajE-Bs/article/view/221/192.

Bakar, A., & Gadi, M. B. (2016). Urban outdoor thermal comfort of the hot-humid region. *MATEC web of conferences 66, 00084 (IBCC),* 4–10. https://doi.org/10.1051/matecconf/20166600084.

Baklanov, A., Ching, J., Grimmond, C. S. B., & Martilli, A. (2009). *Model urbanization strategy: Summaries, recommendations and requirements. Meteorological and air quality models for urban areas*. Berlin, Heidelberg: Springer151–162. https://doi.org/10.1007/978-3-642-00298-4_15.

Blazejczyk, K., Epstein, Y., Jendritzky, G., Staiger, H., & Tinz, B. (2012). Comparison of UTCI to selected thermal indices. *International Journal of Biometeorology, 56*(3), 515–535. https://doi.org/10.1007/s00484-011-0453-2.

Brager, G. S., & de Dear, R. J. (1998). Thermal adaptation in the built environment: A literature review. *Energy and Buildings, 27*, 83–96. https://doi.org/10.1016/S0378-7788(97)00053-4.

Bruse, M., & Fleer, H. (1998). Simulating surface-plant-air interactions inside urban environments with a three dimensional numerical model. *Environmental Modelling and Software, 13*(3–4), 373–384. https://doi.org/10.1016/S1364-8152(98)00042-5.

Chen, Y.-C., & Matzarakis, A. (2014). Modification of physiologically equivalent temperature. *Journal of Heat Island Institute International, 9*(2), 26–32. Retrieved from http://www.heat-island.jp/web_journal/Special_Issue_7JGM/15_chen.pdf.

Chen, L., & Ng, E. (2012). Outdoor thermal comfort and outdoor activities: A review of research in the past decade. *Cities, 29*(2), 118–125. https://doi.org/10.1016/j.cities.2011.08.006.

Chen, F., Kusaka, H., Bornstein, R., Ching, J., Grimmond, C. S. B., Grossman-Clarke, S., ... Zhang, C. (2011). The integrated WRF/urban modelling system: Development, evaluation, and applications to urban environmental problems. *International Journal of Climatology, 31*(2), 273–288. https://doi.org/10.1002/joc.2158.

Cheng, V., Ng, E., Chan, C., & Givoni, B. (2012). Outdoor thermal comfort study in a sub-tropical climate: A longitudinal study based in Hong Kong. *International Journal of Biometeorology, 56*(1), 43–56. https://doi.org/10.1007/s00484-010-0396-z.

Chow, W. T. L., Akbar, S. N. A. B. A., Heng, S. L., & Roth, M. (2016). Assessment of measured and perceived microclimates within a tropical urban forest. *Urban Forestry and Urban Greening, 16*, 62–75. https://doi.org/10.1016/j.ufug.2016.01.010.

de Freitas, C. R., & Grigorieva, E. A. (2015). A comprehensive catalogue and classification of human thermal climate indices. *International Journal of Biometeorology, 59*(1), 109–120. https://doi.org/10.1007/s00484-014-0819-3.

Department of Economic and Social Affairs, Population Department of United Nations (2014). World urbanization prospects. *Demographic Research, 12*, 32. https://doi.org/10.4054/DemRes.2005.12.9.

Din, M. F. M., Lee, Y. Y., Ponraj, M., Ossen, D. R., Iwao, K., Chelliapan, S., ... Chelliapan, S. (2014). Thermal comfort of various building layouts with a proposed discomfort index range for tropical climate. *Journal of Thermal Biology, 41*(1), 6–15. https://doi.org/10.1016/j.jtherbio.2014.01.004.

Eliasson, I. (2000). The use of climate knowledge in urban planning. *Landscape and Urban Planning, 48*(1–2), 31–44. https://doi.org/10.1016/S0169-2046(00)00034-7.

Emmanuel, R. (2005). *An urban approach to climate-sensitive design: Strategies for the tropics – M. Rohinton Emmanuel – Google books.* Retrieved fromTaylor & Francishttps://books.google.com.my/books?hl=en&lr=&id=D7OJ23XA-18C&oi=fnd&pg=PR9&dq=emmanuel+2012+urban+approach+to+climate+sensitive+design&ots=

VJnE4lK048&sig=E66lgchZgMXU_iU2jhiH-cwI83M&redir_esc=y#v=onepage&q&f=false.
Emmanuel, R., Rosenlund, H., & Johansson, E. (2007). Urban shading – A design option for the tropics? A study in Colombo, Sri Lanka. *International Journal of Climatology, 27*, 1995–2004. https://doi.org/10.1002/joc.1609 John Wiley & Sons, Ltd.
Epstein, Y., & Moran, D. S. (2006). Thermal comfort and the heat stress indices. *Industrial Health, 44*(3), 388–398. https://doi.org/10.2486/indhealth.44.388.
Fanger, P. O. (1970). *Analysis and applications in environmental engineering.* Retrieved fromCopenhagen: Danish Technical Press. https://www.cabdirect.org/cabdirect/abstract/19722700268.
Fiala, D., Lomas, K. J., & Stohrer, M. (1999). A computer model of human thermoregulation for a wide range of environmental conditions: The passive system. *Journal of Applied Physiology (Bethesda, Md.: 1985), 87*(5), 1957–1972. Retrieved from http://www.ncbi.nlm.nih.gov/sites/entrez?Db=pubmed&DbFrom=pubmed&Cmd=Link&LinkName=pubmed_pubmed&LinkReadableName=RelatedArticles&IdsFromResult=10562642&ordinalpos=3&itool=EntrezSystem2.PEntrez.Pubmed.Pubmed_ResultsPanel.Pubmed_RVDocSum.
Girgis, N., Elariane, S., Elrazik, M. A., & Abd Elrazik, M. (2016). Evaluation of heat exhausts impacts on pedestrian thermal comfort. *Sustainable Cities and Society, 27*, 152–159. https://doi.org/10.1016/j.scs.2015.06.010.
Givoni, B., Noguchi, M., Saaroni, H., Pochter, O., Yaakov, Y., Feller, N., ... Becker, S. (2003). Outdoor comfort research issues. *Energy and Buildings, 35*, 77–86. https://doi.org/10.1016/S0378-7788(02)00082-8.
Google Map (2017). [The region of SEA]. Retrieved from https://www.google.com/maps/place/South+East+Asia/@6.9960791,113.2395013,4.91z/data=!4m5!3m4!1s0x3233af605e720cd5:0x28a70f18542d1b91!8m2!3d-2.2179704!4d115.66283.
Grant, J. B., Zapata, L. Y., & Middleton, K. M. (2010). CFD and particle image velocimetry in design optimization. *Proceedings of the ASME 2010 International Mechanical Engineering Congress & Exposition*. Retrieved from http://www.interactiveflows.com/downloads/papers/IMECE.pdf.
Grimmond, C. S. B., Blackett, M., Best, M. J., Barlow, J., Baik, J.-J., Belcher, S. E., ... Zhang, N. (2010). The international urban energy balance models comparison project: First results from phase 1. *Journal of Applied Meteorology and Climatology, 49*(6), 1268–1292. https://doi.org/10.1175/2010JAMC2354.1.
Hanipah, M. H., Abdullah, A. H., Che Sidik, N. A., Yunus, R., Azam Yasin, M. N., & Muhammad Yazid, M. N. A. W. (2016). Assessment of outdoor thermal comfort and wind characteristics at three different locations in peninsular Malaysia. *MATEC web of conferences,* 47. https://doi.org/10.1051/matecconf/20164704005 04005.
Honjo, T. (2009). *Thermal comfort in outdoor environment*, *vol. 13*, Global Environmental Research ©2009 AIRIES43–47. https://doi.org/10.6090/jarq.50.101.
Höppe, P. (1999). The physiological equivalent temperature – A universal index for the biometeorological assessment of the thermal environment. *International Journal of Biometeorology, 43*(2), 71–75. https://doi.org/10.1007/s004840050118.
Hoppe, P. (2002). Different aspects of assessing indoor and outdoor thermal comfort. *Energy and Buildings, 34*(6), 661–665. https://doi.org/10.1016/s0378-7788(02)00017-8.
Huizenga, C., Hui, Z., & Arens, E. (2001). A model of human physiology and comfort for assessing complex thermal environments. *Building and Environment, 36*(6), 691–699. https://doi.org/10.1016/S0360-1323(00)00061-5.
Hwang, R. L., & Lin, T. P. (2007). Thermal comfort requirements for occupants of semi-outdoor and outdoor environments in hot-humid regions. *Architectural Science Review, 50*(4), 357–364. https://doi.org/10.3763/asre.2007.5043.
Ignatius, M., Wong, N. H., & Jusuf, S. K. (2015). Urban microclimate analysis with consideration of local ambient temperature, external heat gain, urban ventilation, and outdoor thermal comfort in the tropics. *Sustainable Cities and Society, 19*, 121–135. https://doi.org/10.1016/j.scs.2015.07.016.
Jabarudin, W. W. M. T. W., & Harith, Z. Y. H. (2015). Evaluation on the thermal comfort from reviews and simulation at seaside resorts. In M. Y. Abbas (Vol. Ed.), *Asia Pacific international conference on environment-behaviour studies: Vol. 168*, (pp. 104–115). Amsterdam: Elsevier Science Bv. https://doi.org/10.1016/j.sbspro.2014.10.215.
Jendritzky, G., & Dear, R. (2009). *Adaptation and thermal environment. Biometeorology for adaptation to climate variability and change*, *Vol. 1*, 9–32. https://doi.org/10.1007/978-1-4020-8921-3_2.
Jendritzky, G., de Dear, R., & Havenith, G. (2012). UTCI—Why another thermal index? *International Journal of Biometeorology, 56*(3), 421–428. https://doi.org/10.1007/s00484-011-0513-7.
Johansson, E., & Emmanuel, R. (2006). The influence of urban design on outdoor thermal comfort in the hot, humid city of Colombo, Sri Lanka. *International Journal of Biometeorology, 51*(2), 119–133. https://doi.org/10.1007/s00484-006-0047-6.
Kakon, A. N., Mishima, N., & Kojima, S. (2009). Simulation of the urban thermal comfort in a high density tropical city: Analysis of the proposed urban construction rules for Dhaka, Bangladesh. *Building Simulation, 2*(4), 291–305. https://doi.org/10.1007/s12273-009-9321-y.
Koerniawan, M. D., & Gao, W. (2014a). *Addressing climate to make better places, thermal comfort in outdoor open space in Mega Kuningan superblock, Jakarta.* Researchgate.Nethttps://doi.org/10.13140/2.1.1504.9927 August.
Koerniawan, M. D., & Gao, W. (2014b). *Thermal comfort and walkability in open spaces of Mega Kuningan superblock in Jakarta.* Researchgate.Nethttps://doi.org/10.13140/2.1.4388.5766 October.
Koerniawan, M. D., & Gao, W. (2015). Thermal comfort investigation in three hot-humid climate theme parks in Jakarta. *American Journal of Environmental Sciences* (September), https://doi.org/10.3844/ofsp.10075.
Kubota, T., & Ahmad, S. (2004). *Wind environment in neighboorhood residential areas in Malaysia; A case study of Johor Bharu Metropolitan City. The 5th international seminar on sustainable environmental architecture*.
Kurazumi, Y., Ishii, J., Fukagawa, K., Kondo, E., & Aruninta, A. (2016). *Ethnic differences in thermal responses between Thai and Japanese females in tropical urban climate* (March) Retrieved fromFile.Scirp.Org52–68. http://file.scirp.org/pdf/AJCC_20160330155615 22.pdf.
Lin, T. P. (2009). Thermal perception, adaptation and attendance in a public square in hot and humid regions. *Building and Environment, 44*(10), 2017–2026. https://doi.org/10.1016/j.buildenv.2009.02.004.
Lin, T. P., & Matzarakis, A. (2008). Tourism climate and thermal comfort in Sun Moon Lake, Taiwan. *International Journal of Biometeorology, 52*(4), 281–290. https://doi.org/10.1007/s00484-007-0122-7.
Lin, T. P., Matzarakis, A., & Hwang, R.-L. L. (2010). Shading effect on long-term outdoor thermal comfort. *Building and Environment, 45*(1), 213–221. https://doi.org/10.1016/j.buildenv.2009.06.002.
Lin, C. H., Lin, T. P., & Hwang, R. L. (2013). Thermal comfort for urban parks in subtropics: Understanding visitor's perceptions, behavior and attendance. *Advances in Meteorology, 8*. https://doi.org/10.1155/2013/640473.
Liu, Z., Zheng, S., & Zhao, L. (2018). Evaluation of the ENVI-met vegetation model of four common tree species in a subtropical hot-humid area. *Atmosphere, 9*(5), 198. https://doi.org/10.3390/atmos9050198.
Makaremi, N., Salleh, E., Jaafar, M. Z., & GhaffarianHoseini, A. (2012). Thermal comfort conditions of shaded outdoor spaces in hot and humid climate of Malaysia. *Building and Environment, 48*(1), 7–14. https://doi.org/10.1016/j.buildenv2011.07.024.
Matzarakis, A., Mayer, H., & Iziomon, M. G. (1999). Applications of a universal thermal index: Physiological equivalent temperature. *International Journal of Biometeorology, 43*(2), 76–84. https://doi.org/10.1007/s004840050119.
Matzarakis, A., Rutz, F., & Mayer, H. (2010). Modelling radiation fluxes in simple and complex environments: Basics of the RayMan model. *International Journal of Biometeorology, 54*(2), 131–139. https://doi.org/10.1007/s00484-009-0261-0.
Mayer, H., & Hoppe, P. (1987). Thermal comfort of man in different urban environments. *Theoretical and Applied Climatology, 38*(1), 43–49. https://doi.org/10.1007/bf00866252.
Nieuwolt, S. (1977). *Tropical climatology: An introduction to the climates of the low latitudes.* London; New York: Wiley.
Mirzaei, P. A. (2015). Recent challenges in modeling of urban heat island. *Sustainable Cities and Society, 19*, 200–206. https://doi.org/10.1016/j.scs.2015.04.001.
Mochida, A., & Lun, I. Y. F. F. (2008). Prediction of wind environment and thermal comfort at pedestrian level in urban area. *Journal of Wind Engineering and Industrial Aerodynamics, 96*(10–11), 1498–1527. https://doi.org/10.1016/j.jweia.2008.02.033.
Morris, K. I., Chan, A., Salleh, S. A., Ooi, M. C. G., Oozeer, M. Y., & Abakr, Y. A. (2016). Numerical study on the urbanization of Putrajaya and its interaction with the local climate, over a decade. *Urban Climate, 16*, 1–24. https://doi.org/10.1016/j.uclim.2016.02.001.
Morris, K. I., Chan, A., Morris, K. J. K., Ooi, M. C. G. G., Oozeer, M. Y., Abakr, Y. A., ... Al-Qrimli, H. F. (2017). Impact of urbanization level on the interactions of urban area, the urban climate, and human thermal comfort. *Applied Geography, 79*, 50–72. https://doi.org/10.1016/j.apgeog.2016.12.007.
Nakano, J. (2003). *Evaluation of thermal comfort in semi-outdoor environment Junta Nakano* (March) Retrieved fromhttp://www.wul.waseda.ac.jp/gakui/honbun/3534/3534.pdf.
Nakano, A. (2015). *Urban weather generator user interface development: Towards a usable tool for integrating urban heat island effect within urban design process.* Retrieved fromhttps://dspace.mit.edu/handle/1721.1/99251.
Nasir, R. A., Ahmad, S. S., & Ahmed, A. Z. (2012). Psychological Adaptation of Outdoor Thermal Comfort in Shaded Green Spaces in Malaysia. *Procedia – Social and Behavioral Sciences, 68*, 865–878. https://doi.org/10.1016/j.sbspro.2012.12.273.
Nasir, R. A., Ahmad, S. S., & Ahmed, A. Z. (2013a). Physical activity and human comfort correlation in an urban park in hot and humid conditions. *Procedia – Social and Behavioral Sciences, 105*, 598–609. https://doi.org/10.1016/j.sbspro.2013.11.063.
Nasir, R. A., Ahmad, S. S., & Ahmed, A. Z. (2013b). Perceived and measured adaptive thermal comfort at an outdoor shaded recreational area in Malaysia. *Advanced Materials Research, 610–613*, 1083–1086. https://doi.org/10.4028/www.scientific.net/AMR.610-613.1083.
Ndetto, E. L., & Matzarakis, A. (2017). Assessment of human thermal perception in the hot-humid climate of Dar es Salaam, Tanzania. *International Journal of Biometeorology, 61*(1), 69–85. https://doi.org/10.1007/s00484-016-1192-1.
Nikolopoulou, M., & Lykoudis, S. (2006). Thermal comfort in outdoor urban spaces: Analysis across different European countries. *Building and Environment, 41*(11), 1455–1470. https://doi.org/10.1016/j.buildenv.2005.05.031.
Nikolopoulou, M., & Steemers, K. (2003). Thermal comfort and psychological adaptation as a guide for designing urban spaces. *Energy and Buildings, 35*(1), 95–101. https://doi.org/10.1016/s0378-7788(02)00084-1.
Nikolopoulou, M., Baker, N., & Steemers, K. (2001). Thermal comfort in outdoor urban spaces: Understanding the human parameter. *Solar Energy, 70*(3), 227–235. https://doi.org/10.1016/s0038-092x(00)00093-1.
Nordin, M. A. B. C., & Hassan, H. (2015). Application of Markov Chain Model to daily maximum temperature for thermal comfort in Malaysia. I. Mohamed, L. T. How, A. C. Y. Mui, & W. K. Bin (Eds.). *22nd national symposium on mathematical sciences, Vol. 1682.* https://doi.org/10.1063/1.4932504 p. 050013.
Oke, T. R. (2006). Towards better scientific communication in urban climate. *Theoretical and Applied Climatology, 84*(1–3), 179–190. https://doi.org/10.1007/s00704-005-0153-0.
Oke, T. R., & Stewart, I. D. (2012). Local climate zone for urban temperature studies. *Bulletin of the American Meteorological Society,* 1879–1900. https://doi.org/10.1175/BAMS-D-11-00019.1 Retrieved from.
Parson, K. (2003). *Human thermal environments the effects of hot, moderate, and cold.* Retrieved from3–4. https://books.google.com.my/books?hl=en&lr=&id=

WejMAwAAQBAJ&oi=fnd&pg=PP1&dq=Parson+K+2003+human+thermal+environments&ots=hmqpcSjuB3&sig=l2HSRt0X6KKIBPdA2fqJ0XEs5AE&redir_esc=y#v=onepage&q&f=true.

Peel, M. C., Finlayson, B. L., & Mcmahon, T. A. (2007). Updated world map of the Koppen-Geiger climate classification. *Hydrol. Earth Syst. Sci. Discuss, 4*, 439–473. https://doi.org/10.1127/0941-2948/2006/0130.

Peng, L. L. H., & Jim, C. Y. (2013). Green-roof effects on neighborhood microclimate and human thermal sensation. *Energies, 6*(2), 598–618. https://doi.org/10.3390/en6020598.

Qaid, A., Bin Lamit, H., Ossen, D. R., Raja Shahminan, R. N., & Shahminan, R. N. R. (2016). Urban heat island and thermal comfort conditions at micro-climate scale in a tropical planned city. *Energy and Buildings, 133*, 577–595. https://doi.org/10.1016/j.enbuild.2016.10.006.

Quayle, R., & Doehring, F. (1981). Heat stress. a comparison of indices. *Weatherwise, 34*(3), 120–124. https://doi.org/10.1080/00431672.1981.9931958.

Ramakreshnan, L., Aghamohammadi, N., Fong, C. S., Bulgiba, A., Zaki, R. A., Wong, L. P., ... Sulaiman, N. M. (2017). Haze and health impacts in ASEAN countries: A systematic review. *Environmental Science and Pollution Research,* 1–16. https://doi.org/10.1007/s11356-017-0860-y.

Ramakreshnan, L., Aghamohammadi, N., Fong, C. S., Ghaffarianhoseini, A., Ghaffarianhoseini, A., Wong, L. P., ... Sulaiman, N. M. (2018). A critical review of urban heat island phenomenon in the context of greater Kuala Lumpur, Malaysia. *Sustainable Cities and Society, 39*, 99–113. https://doi.org/10.1016/j.scs.2018.02.005.

Ramakreshnan, L., Aghamohammadi, N., Fong, C. S., Ghaffarianhoseini, A., Wong, L. P., & Sulaiman, N. M. (2019). Empirical study on temporal variations of canopy-level Urban Heat Island effect in the tropical city of Greater Kuala Lumpur. *Sustainable Cities and Society, 44*, 748–762. https://doi.org/10.1016/J.SCS.2018.10.039.

Roshan, G., & Nastos, P. T. (2018). Assessment of extreme heat stress probabilities in Iran's urban settlements, using first order Markov chain model. *Sustainable Cities and Society, 36*, 302–310. https://doi.org/10.1016/j.scs.2017.10.013.

Roth, M. (2007). Review of urban climate research in (sub) tropical regions. *International Journal of Climatology, 27*(14), 1859–1873. https://doi.org/10.1002/joc.

Roth, M., & Chow, W. T. L. (2012). A historical review and assessment of urban heat island research in Singapore. *Singapore Journal of Tropical Geography, 33*(3), 381–397. https://doi.org/10.1111/sjtg.12003.

Sanesi, G., Lafortezza, R., Bonnes, M., & Carrus, G. (2006). Comparison of two different approaches for assessing the psychological and social dimensions of green spaces. *Urban Forestry & Urban Greening, 5*(3), 121–129. https://doi.org/10.1016/j.ufug.2006.06.001.

Siemens, A. (2011). Asian Green City Index assessing the environmental performance of Asia's major cities. *Siemens AG,* 1–123. https://doi.org/10.1787/5kg0tflmzx34-en.

Sohar, E., Tennenbaum, J., & Robinson, N. (1962). *A comparison of the Cumulative Discomfort Index (Cum. D.I.) and Cumulative Effective Temperature (Cum. E.T.), as obtained by meteorological data. Biometeorology*. Elsevier395–400. https://doi.org/10.1016/B978-0-08-009683-4.50052-8.

Spagnolo, J., & de Dear, R. (2003). A field study of thermal comfort in outdoor and semi-outdoor environments in subtropical Sydney Australia. *Building and Environment, 38*(5), 721–738. https://doi.org/10.1016/s0360-1323(02)00209-3.

Tan, C. L., Wong, N. H., & Jusuf, S. K. (2013). Outdoor mean radiant temperature estimation in the tropical urban environment. *Building and Environment, 64*, 118–129. https://doi.org/10.1016/j.buildenv.2013.03.012.

Thom, E. C. (1959). The discomfort index. *Weatherwise, 12*(2), 57–61. https://doi.org/10.1080/00431672.1959.9926960.

Thorsson, S., Lindberg, F., Eliasson, I., & Holmer, B. (2007). Different methods for estimating the mean radiant temperature in an outdoor urban setting. *International Journal of Climatology, 27*, 1983–1993. https://doi.org/10.1002/joc.1537 John Wiley & Sons, Ltd.

Van Doan, Q., Kusaka, H., & Ho, Q. B. (2016). Impact of future urbanization on temperature and thermal comfort index in a developing tropical city: Ho Chi Minh City. *Urban Climate, 17*, 20–31. https://doi.org/10.1016/j.uclim.2016.04.003.

Vescovi, F. (2013). *Designing the urban renaissance: Sustainable and competitive place making in England. Designing the urban renaissance: Sustainable and competitive place making in England, Vol. 5*https://doi.org/10.1007/978-94-007-5631-1.

Wilby, R. (2007). A review of climate change impacts on the built environment. *Built Environment, 33*(1), 31–45. https://doi.org/10.2148/benv.33.1.31.

Wong, N. H., Ignatius, M., Eliza, A., Jusuf, S. K., & Samsudin, R. (2012). Comparison of steve and envi-met as temperature prediction models for singapore context. *International Journal of Sustainable Building Technology and Urban Development, 3*(3), 197–209. https://doi.org/10.1080/2093761X.2012.720224.

World Bank Indicator (2017). *World Development Indicators | Data.* Retrieved January 8, 2018, fromhttps://data.worldbank.org/data-catalog/world-development-indicators.

Yang, W., Wong, N. H., & Jusuf, S. K. (2013a). Thermal comfort in outdoor urban spaces in Singapore. *Building and Environment, 59*, 426–435. https://doi.org/10.1016/j.buildenv.2012.09.008f.

Yang, W., Wong, N. H., & Zhang, G. (2013b). A comparative analysis of human thermal conditions in outdoor urban spaces in the summer season in Singapore and Changsha, China. *International Journal of Biometeorology, 57*(6), 895–907. https://doi.org/10.1007/s00484-012-0616-9.

Yang, W., Wong, N. H., & Lin, Y. L. (2015). Thermal comfort in high-rise urban environments in Singapore. Y. Sun, & J. Pei (Eds.). *9th international symposium on heating, ventilation and air conditioning, Vol. 121*, 2125–2131. https://doi.org/10.1016/j.proeng.2015.09.083.

Yang, J., Nam, I., & Sohn, J. R. (2016). The influence of seasonal characteristics in elderly thermal comfort in Korea. *Energy and Buildings, 128*, 583–591. https://doi.org/10.1016/j.enbuild.2016.07.037.

Yang, L., Niyogi, D., Tewari, M., Aliaga, D., Chen, F., Tian, F. Q., ... Ni, G. H. (2016). Contrasting impacts of urban forms on the future thermal environment: Example of Beijing metropolitan area. *Environmental Research Letters, 11*(3), 10. https://doi.org/10.1088/1748-9326/11/3/034018.

Yang, W., Wong, N. H., & Li, C.-Q. (2016). Effect of street design on outdoor thermal comfort in an urban street in Singapore. *Journal of Urban Planning and Development, 142*(1), 05015003. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000285.